APPENDIX G
MANOMETER TESTING

APPENDIX G

Soil Vapor Well Response to Barometric Pressure Changes and Landfill Gas Extraction System Operation

General

A study was performed at the Poway Landfill between 10 April and 12 May 2006 to evaluate the response of soil vapor wells to the landfill gas (LFG) extraction system. Soil vapor wells are screened within different media at several locations at the site, including:

- Within the waste near the toe of the landfill (PVP-7A, PVP-8, PVP-9, and PVP-10A);
- In soil underlying the waste (PVP-7B and PVP-10B); and
- In native soil outside of the landfill waste footprint (PVP-1, PVP-1A, PVP-2A, PVP-2B, PVP-3A, PVP-3B, PVP-4A, PVP-4B, and PVP-5).

Results of the study were analyzed to qualitatively evaluate: 1) the influence of the LFG extraction system within the waste; 2) the permeability of the landfill cap; and 3) the pneumatic connectivity between the soil vapor wells and the atmosphere.

Field Methods

A field micromanometer (manometer) equipped with a data logging feature was utilized to measure and record the pressure differential between the atmosphere and the soil vapor wells. The TSI Incorporated model 8705 DP-CALC manometer collected differential pressure data in units of inches of water column (in-WC) with a precision of 0.0001 in-WC. A Barnstead International model PRTEMP 101 "barologger" was utilized to simultaneously measure and record barometric pressure and temperature. Barometric pressures were collected in units of pounds per square inch (psi), which were converted to units of in-WC for comparison with manometric pressures.

Each manometer has two ports, either of which may be connected to a soil vapor well or left exposed to ambient barometric pressure. For each soil vapor well test, the positive manometer port was connected to the dedicated soil vapor well tubing while the negative port was allowed to equilibrate to the atmosphere. For this configuration, the manometric pressure is the difference in the barometric (atmospheric) pressure and the soil vapor well absolute pressure (the pressure inside the medium in the vicinity of the soil vapor well screen).

The pressures in up to three soil vapor wells were simultaneously monitored with separate manometers during each test. Each manometer and data logger was stored in the vault of the vapor well being analyzed for security purposes and to protect the instrument from weather. To allow the pressure inside each vault to equilibrate with the outside barometric pressure, one bolt of the vault was removed, thereby leaving a small opening (bolt hole) in the lid.

A total of fourteen tests were performed. During an initial stage of testing, which occurred from 10 through 21 April 2006, each soil vapor well was tested at least once. A second phase of testing was performed from 05 through 12 May 2006. Tests were typically performed for approximately 24-hour periods, usually starting after the LFG extraction system turned off each afternoon. The 24-hour monitoring period allowed evaluation of the soil vapor well pressure response for a full LFG extraction system daily operational cycle. The automated LFG extraction system typically started each day at approximately 5:30 am and shut down between approximately 2:25 and 3:00 pm.

At the start of each test, the data logging feature was initiated. Data were typically recorded every ten minutes for each manometer and the barometer. At the end of each test, the instruments were retrieved from the vaults and the data were downloaded to a laptop computer

Interpretation Methods

Barometric pressures and soil vapor well absolute pressures were utilized to analyze the response in each soil vapor well to barometric changes. Barometric (atmospheric pressure) and manometric (pressures differences measured between soil vapor wells and barometric pressure) pressures were recorded directly. The soil vapor well absolute pressure was then calculated by adding the manometric pressure to the barometric pressure, as shown in the following equation:

$$P_{vaporwell} = P_{baro} + M$$

Where the variables are defined as follows:

$P_{vapor\ well}$ = *calculated soil vapor well absolute pressure (in-WC);*
P_{baro} = *barometric pressure (in-WC); and*
M = *manometric pressure (in-WC).*

Note that:

$$M = \Delta P = P_{vaporwell} - P_{baro}$$

The manometric pressure is therefore equal to typical "gauge" pressure (pressure relative to the atmosphere).

Figure 1 graphically illustrates the calculation of the soil vapor well absolute pressure curve. A negative manometric pressure is indicative of a soil vapor well absolute pressure that is less than the atmospheric pressure, i.e., the soil vapor well is under a vacuum. A positive manometric pressure is indicative of a soil vapor well absolute pressure that is greater than the atmospheric pressure, i.e. the soil vapor well is under positive pressure. In addition, the amplitude of the manometric pressures is indicative of the pneumatic connectivity between the soil vapor well and the atmosphere and may therefore provide an indirect qualitative assessment of the relative permeability of the media between the soil vapor well and land surface.

Because soil vapor well absolute pressures are calculated relative to the observed barometric pressures, evaluation of the changes in barometric pressure is important in the analysis of the data. For soil vapor wells screened in media that have a relatively high pneumatic connectivity with the atmosphere, pressure or vacuum should not build up as the barometric pressure changes. For this situation, the amplitude of the manometric pressures should be relatively low (Figure 2). Observation of relatively low manometric pressure amplitudes may suggest that relatively high-permeability media exist between the soil vapor well and the atmosphere. Conversely, manometric pressures for soil vapor wells screened in media that are more pneumatically isolated from the atmosphere should have larger amplitudes when the barometric pressure fluctuates (Figure 3). Observation of relatively high manometric pressure amplitudes may suggest that relatively low-permeability media exist between the soil vapor well and the atmosphere.

Results and Analysis

The results of Tests 1 through 14 are presented graphically on Figures 4 A and B through 17 A and B, respectively. Figure A for each test presents the measured barometric pressure and the calculated soil vapor well absolute pressure. Figure B presents the manometric pressure and barometric pressures for each test. Increments on the primary and secondary y-axes were adjusted to be the identical, thereby allowing evaluation of the scale of the pressure response of the soil vapor wells based on the barometric changes. The approximate times that the LFG extraction system started up and shut down during each test are also displayed on each figure.

The results and conclusions of the tests are summarized below for each medium in which the soil vapor wells are screened.

Soil Vapor Wells Screened Within Landfill Waste

For the soil vapor wells screened within the landfill waste, the manometric pressure response to barometric changes appears to be relatively high and occurs with a slight lag time (Figures 4, 5, 9, and 10). The pressure inside the waste typically takes a few hours to respond to the barometric pressure changes. Manometric pressures for soil vapor wells PVP-7A, PVP-9, and PVP-10A generally did not exceed 0.01 in-WC as the barometric pressure fluctuated, suggesting pneumatic connectivity of the landfill waste with the atmosphere. Soil vapor absolute pressures in soil vapor well PVP-8 were generally greater than the barometric pressures, but followed the pattern of the barometric pressure fluctuations (Figure 9A). The greater soil vapor well absolute pressure, relative to barometric pressure, may be the result of lower-permeability waste in the immediate vicinity of vapor well PVP-8, or heterogeneities in the waste and/or landfill cap in the vicinity of vapor well PVP-8, which may have resulted in increased soil vapor well absolute pressure due to LFG generation. Data from soil vapor wells screened within the landfill waste indicate the landfill cap is relatively permeable in the vicinity of these soil vapor wells. The relative permeability of the cap and apparent connectivity with the atmosphere may explain elevated oxygen concentrations observed in the landfill gas extraction wells.

Soil vapor wells PVP-7A, PVP-8, PVP-9, and PVP-10A each showed a response to the operation of the LFG extraction system (Figures 4B, 5B, 9B, and 10B). The slope of the curve of plotted manometric pressures appears to decrease disproportionately to decreases in barometric pressure at the time the LFG system starts up. These data indicate that the influence of the nearby LFG extraction wells extends at least to the locations of these four soil vapor wells. The influence of the LFG extraction wells on the soil vapor wells screened within the waste appears to decrease while the extraction system is operational. This may be due to the LFG extraction system inducing air flow through the relatively permeable landfill cover and thereby reducing the influence of the LFG extraction wells within the waste.

Soil Vapor Wells Screened in Soil Underlying Landfill Waste

In soil vapor wells screened below the landfill waste (PVP-7B and PVP-10B), the response to barometric pressure changes appears to be less than the response observed in the landfill soil vapor wells. The response occurs with a lag time that is slightly longer than observed in soil vapor wells screened in the waste (Figures 5, 6, and 13). Pressure in the soil vapor wells below the waste typically takes one to several hours to equilibrate to changes in barometric pressure. Manometric pressures for soil vapor well PVP-7B varied by as much as 0.05 in-WC (Figure 13) and manometric pressures for PVP-10B varied by as much as 0.1 in-WC (Figures 6B and 13B) as the barometric pressure fluctuated. These manometric pressures suggest that the soil below the waste is pneumatically connected to the atmosphere, but to a lesser extent than the waste, as would be expected.

Soil vapor well PVP-10B showed some response to the operation of the LFG extraction system (Figures 6B and 13B). Soil vapor well PVP-7B, however, showed no conclusive response to LFG system operation (Figure 5B). Manometric pressures in soil vapor well PVP-10B appeared to decrease disproportionately to decreases in barometric pressure at the time the LFG system was reported to start up. These data indicate that the influence of the nearby LFG extraction wells extends vertically downward to beneath the waste in the vicinity of soil vapor well PVP-10B. The LFG extraction well influence appears to be sustained for a longer period of time than observed for soil vapor wells screened within the waste, but the influence does appear to decay after several hours.

Soil Vapor Wells Outside the Landfill Waste Footprint

Most of the soil vapor wells outside the landfill waste footprint responded to barometric changes nearly instantaneously, with the soil vapor well absolute pressures nearly paralleling the barometric pressure (Figures 7, 8, 9, 10, 11, 12, 14, 15, 16, and 17). For soil vapor wells outside the landfill waste footprint (PVP-1, PVP-1A, PVP-2A, PVP-2B, PVP-3A, PVP-4A, and PVP-5), average manometric pressures were less than 0.01 in-WC in amplitude, suggesting that these soil vapor wells are highly pneumatically connected to the atmosphere (Figures 7B, 8B, 9B, 10B, 11B, 12B, 14B, 15B, 16B, and 17B). Manometric pressures for soil vapor well PVP-3B and PVP-4B indicate these soil vapor wells are less connected to the atmosphere than the other soil vapor wells outside the landfill waste footprint (Figures 7B, 8B, and 9B). No responses to operation of the LFG extraction system were observed in the soil vapor wells outside the footprint of the landfill waste.

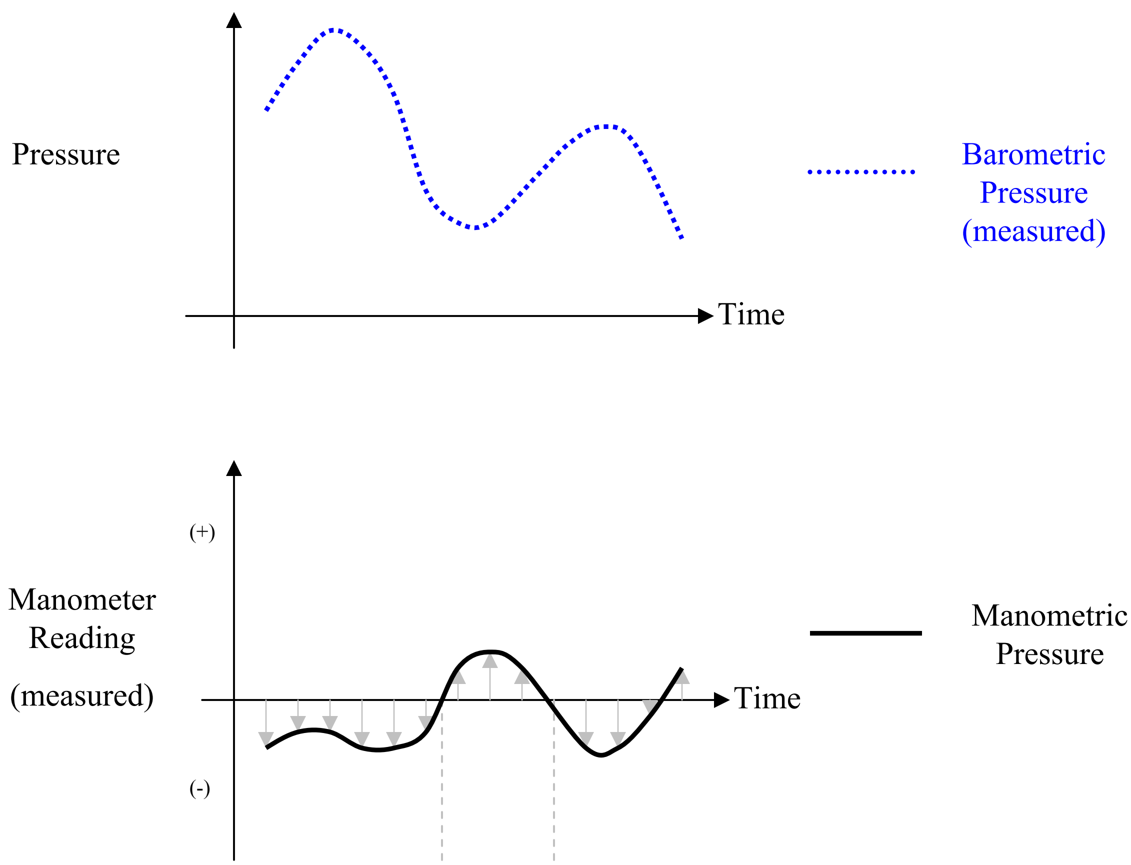
Summary

Each of the soil vapor wells analyzed showed a response to barometric changes; however, the level of the response varied. For some soil vapor wells, responses to the barometric changes occurred with a lag time, sometimes as long as several hours. In general, soil vapor wells screened in similar media showed similar responses. Soil vapor wells screened in the waste showed rapid response to startup of the LFG extraction system, while soil vapor wells screened in soil underlying waste showed a delayed response to system startup. The magnitude of the response to the extraction system of the soil vapor wells screened in waste was greatest shortly after startup and dissipated over the system “on” cycle. Soil vapor wells screened in the soil underlying waste showed a delayed response to LFG extraction system startup. Soil vapor wells outside the limits of landfill waste did not display a discernable response to LFG extraction system operation.

The level of response of each soil vapor well to barometric changes may be a qualitative measurement of the permeability of the media between the soil vapor well and the atmosphere. The response of soil vapor wells screened in the waste to barometric changes suggests that the overlying landfill cap is relatively permeable. Observation of relatively high oxygen concentrations in LFG also suggests that atmospheric air is infiltrating through the landfill cap into the waste.

Although each soil vapor well in the waste showed some response to the LFG extraction system, the lateral extent of the influence beyond the soil vapor wells is not known. The relatively permeable landfill cap may be affecting the radius of influence of the LFG extraction wells within the waste by inducing air flow through the landfill cap. These relative permeabilities may explain the observation of a rapid response to startup of the LFG extraction system followed by a gradual decrease in the extent of the response within the waste. It is possible that when the LFG extraction system starts up, the initial extracted flow is from the most permeable layer, i.e., the waste, but the less permeable upper layer (landfill cap) eventually contributes to the flow, decreasing the flow from within the waste and thereby reducing the radius of influence. Although the LFG extraction system appears to be affecting soils underlying the waste, extraction of vapors from the soil below the waste has the benefit of reducing the potential for LFG to migrate downward through this medium.

Figure 1: Illustrated Method for Determination of Absolute Pressure in Probe.



Adding the manometer reading to the barometric pressure gives the absolute pressure in the medium the probe is screened in…

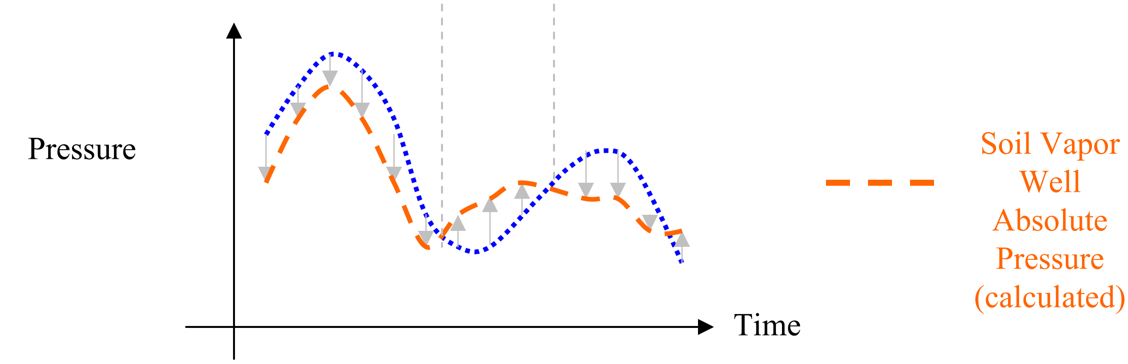
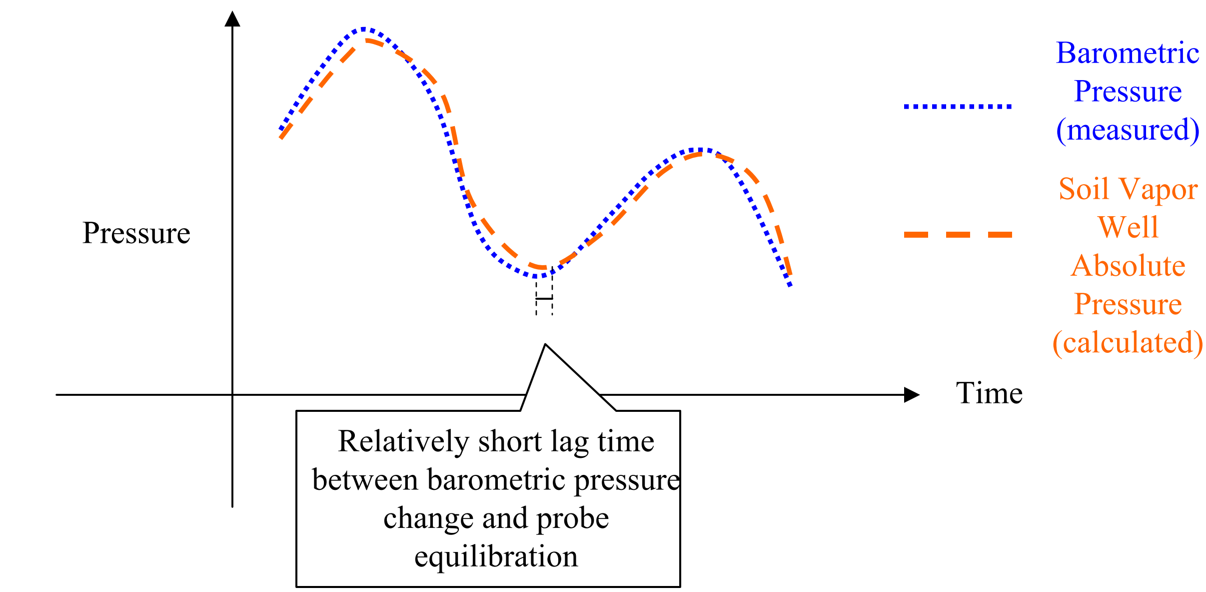


Figure 2: Probe Screened in Medium with <u>Relatively High</u> Pneumatic Connectivity to the Atmosphere.



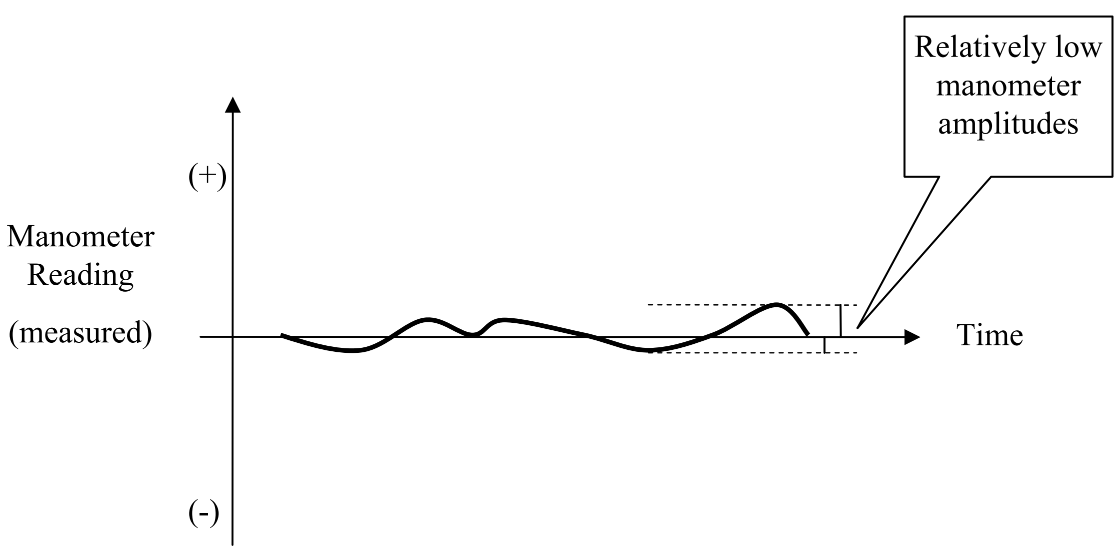
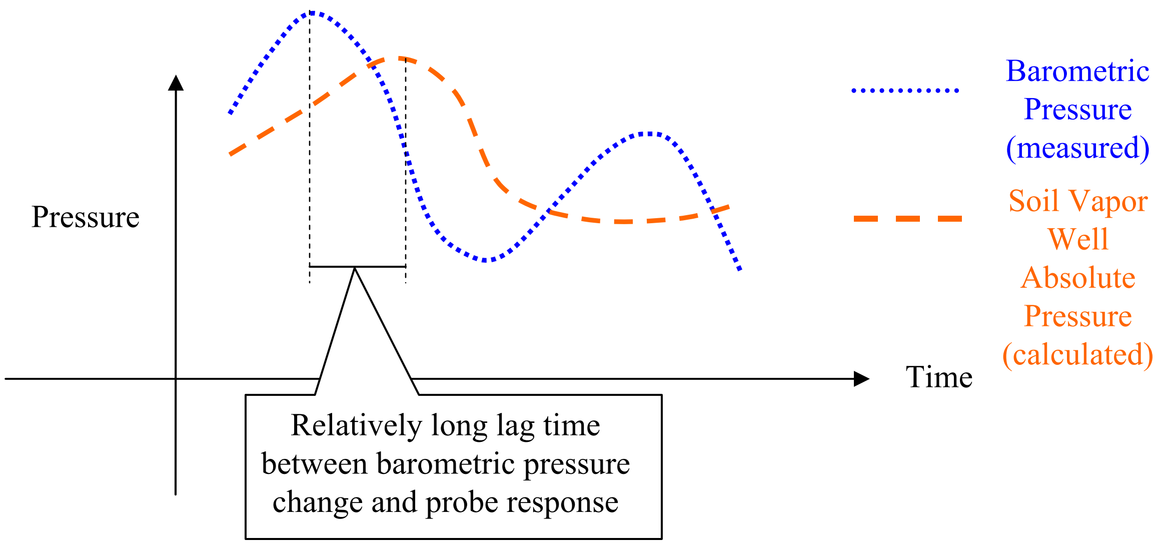
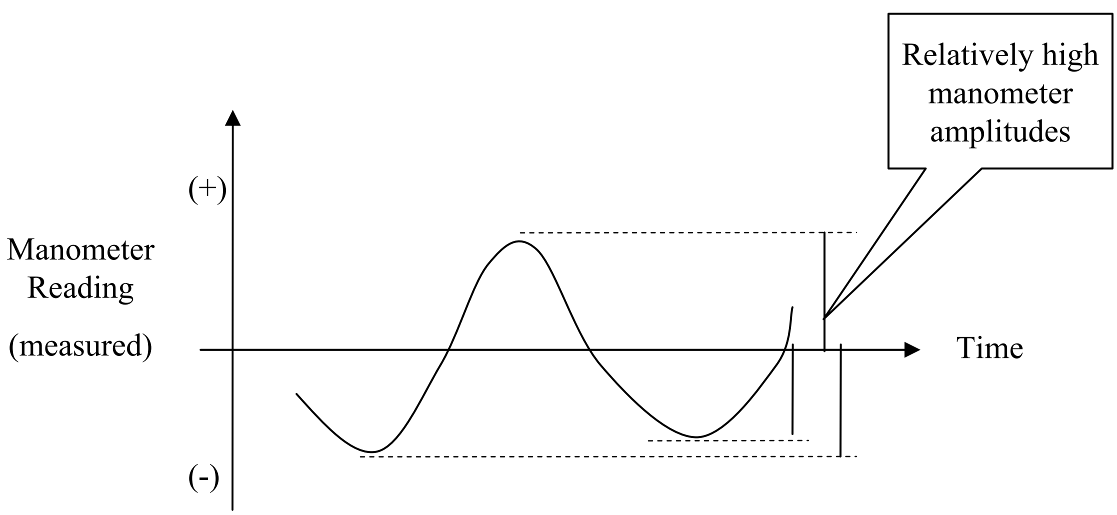


Figure 3: Probe Screened in Medium with <u>Relatively Low</u> Pneumatic Connectivity to the Atmosphere.





Legend for Figures 4A and B through 17A and B

PVP-7A PVP-8 PVP-9 PVP-10A	Soil vapor wells in waste
PVP-7B PVP-10B	Soil vapor wells in soil underlying waste
PVP-1 PVP-1A PVP-2A PVP-2B PVP-3A PVP-3B PVP-4A PVP-4B PVP-5	Soil vapor wells outside of landfill waste footprint
Barometer 1	Atmospheric pressure

Figure 4A
Test 1 Absolute Pressures

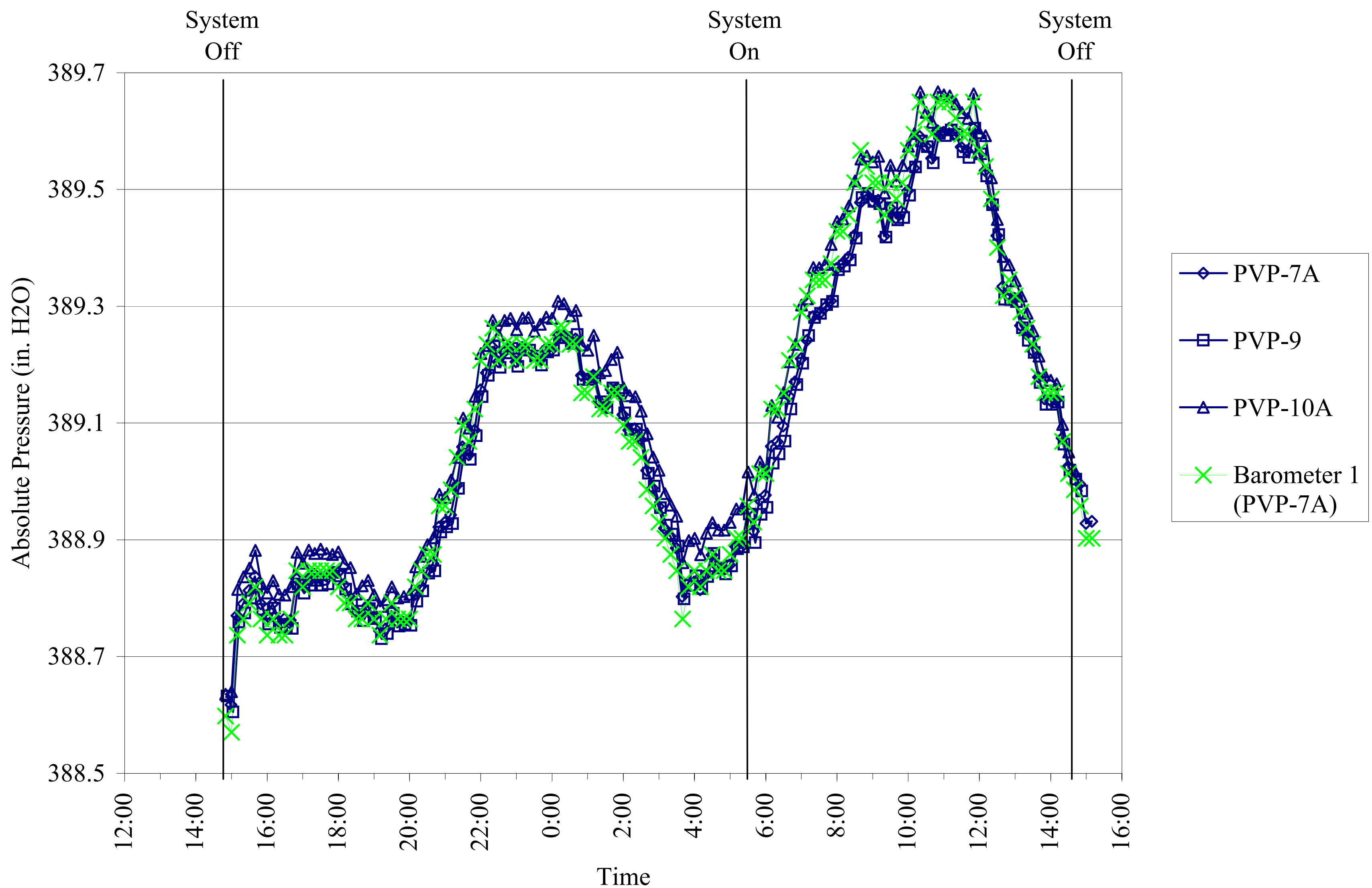


Figure 4B
Test 1 Manometer Data

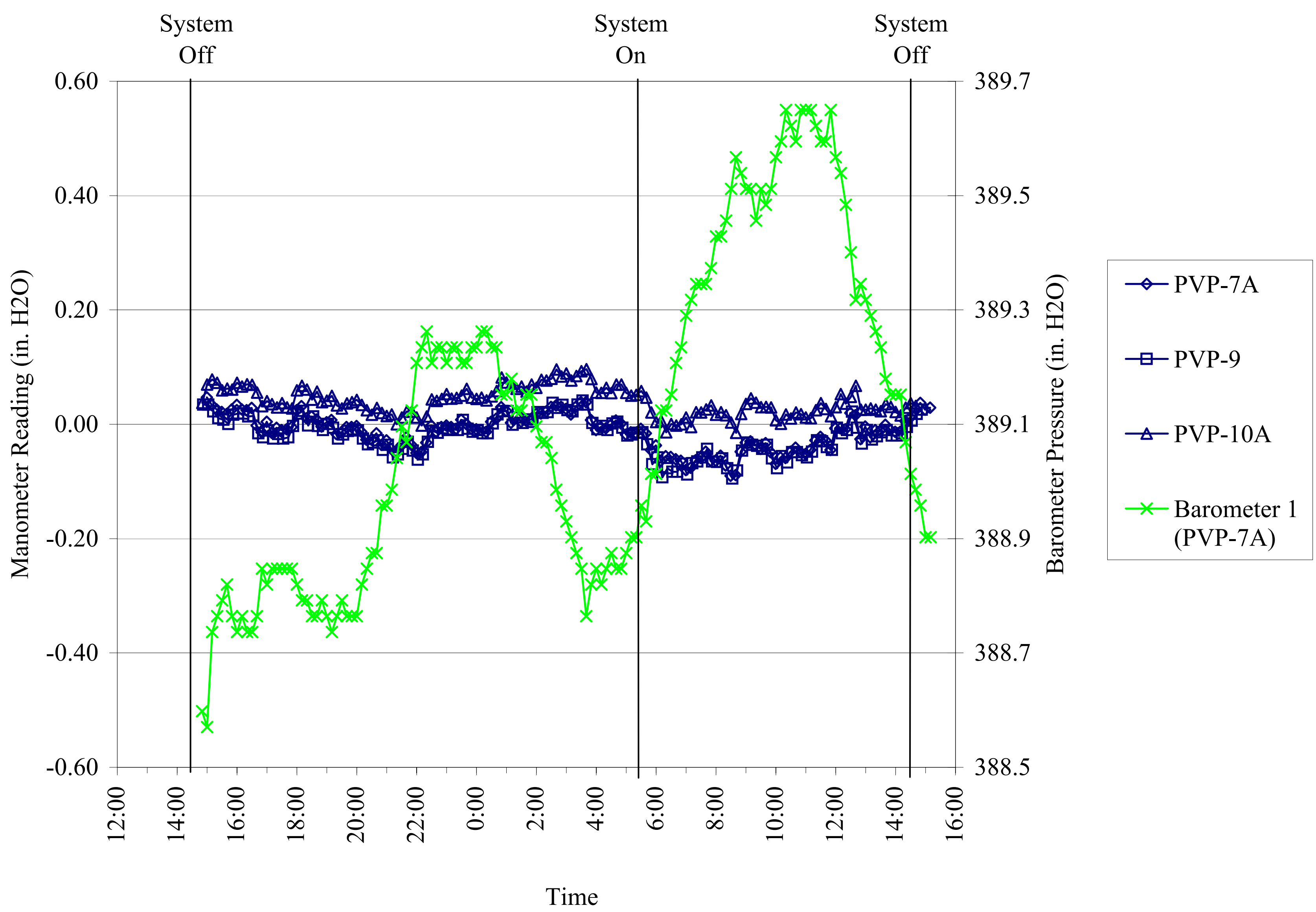


Figure 5A
Test 2 Absolute Pressures

Figure 5B
Test 2 Manometer Data

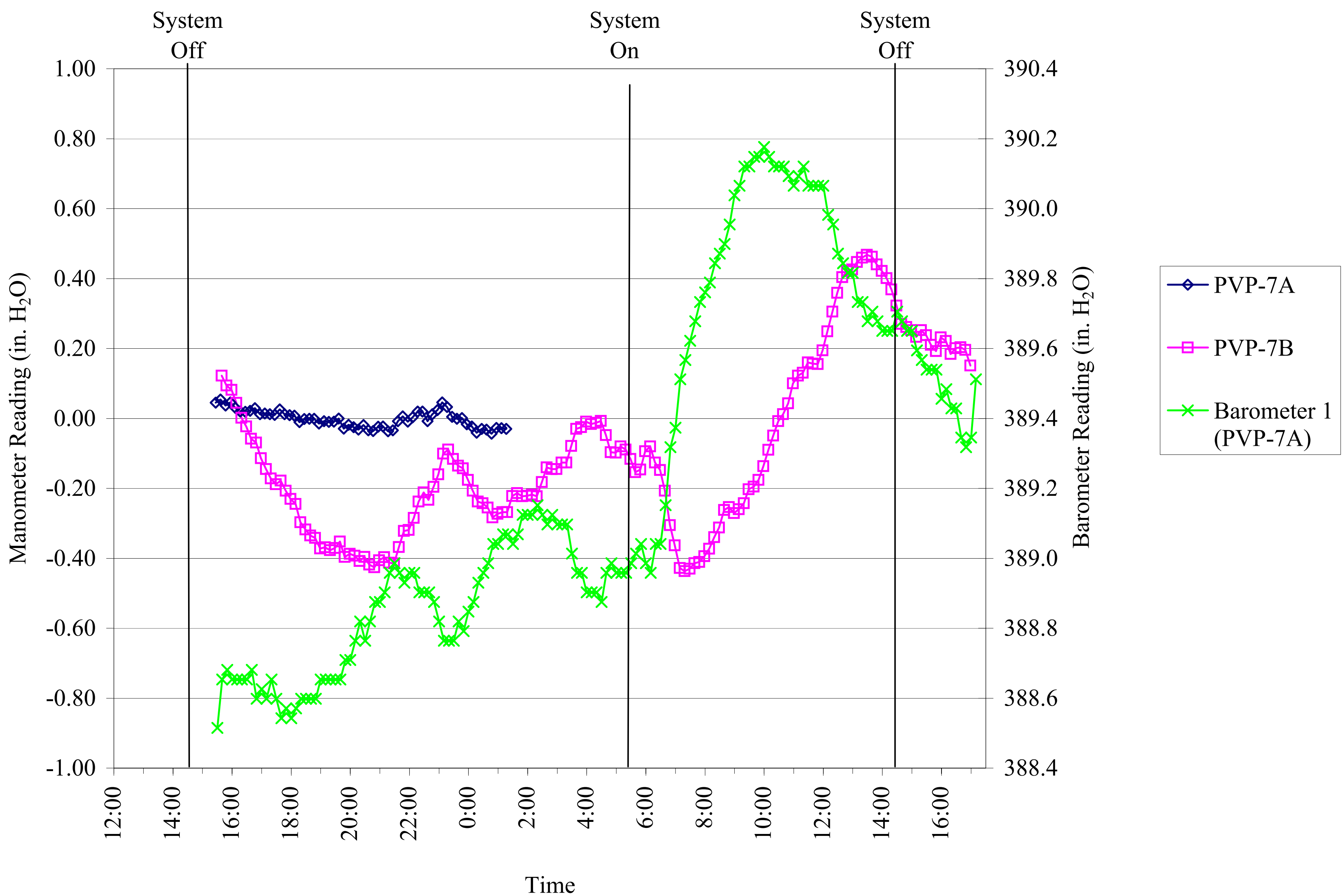


Figure 6A
Test 3 Absolute Pressures

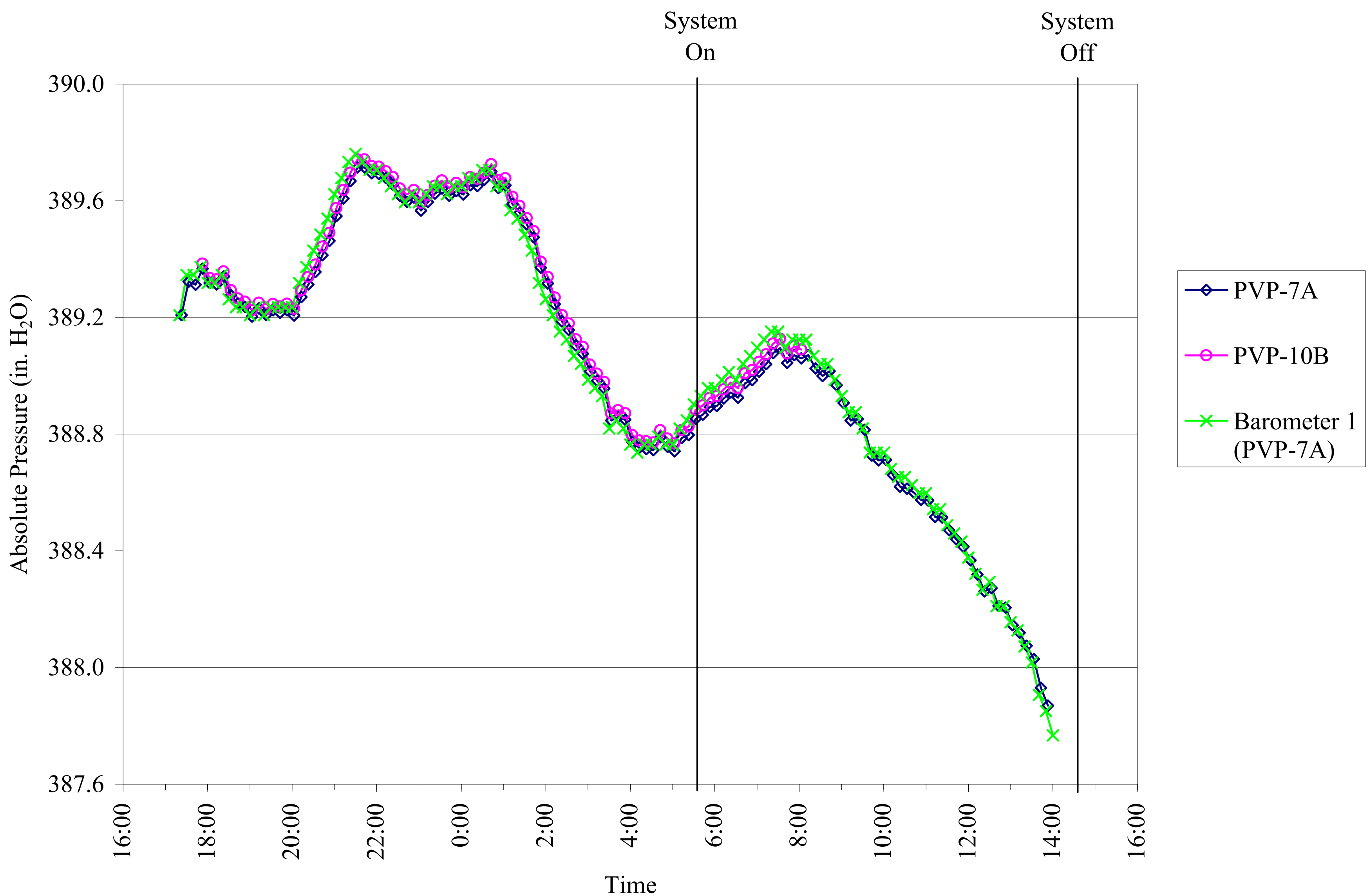


Figure 6B
Test 3 Manometer Data

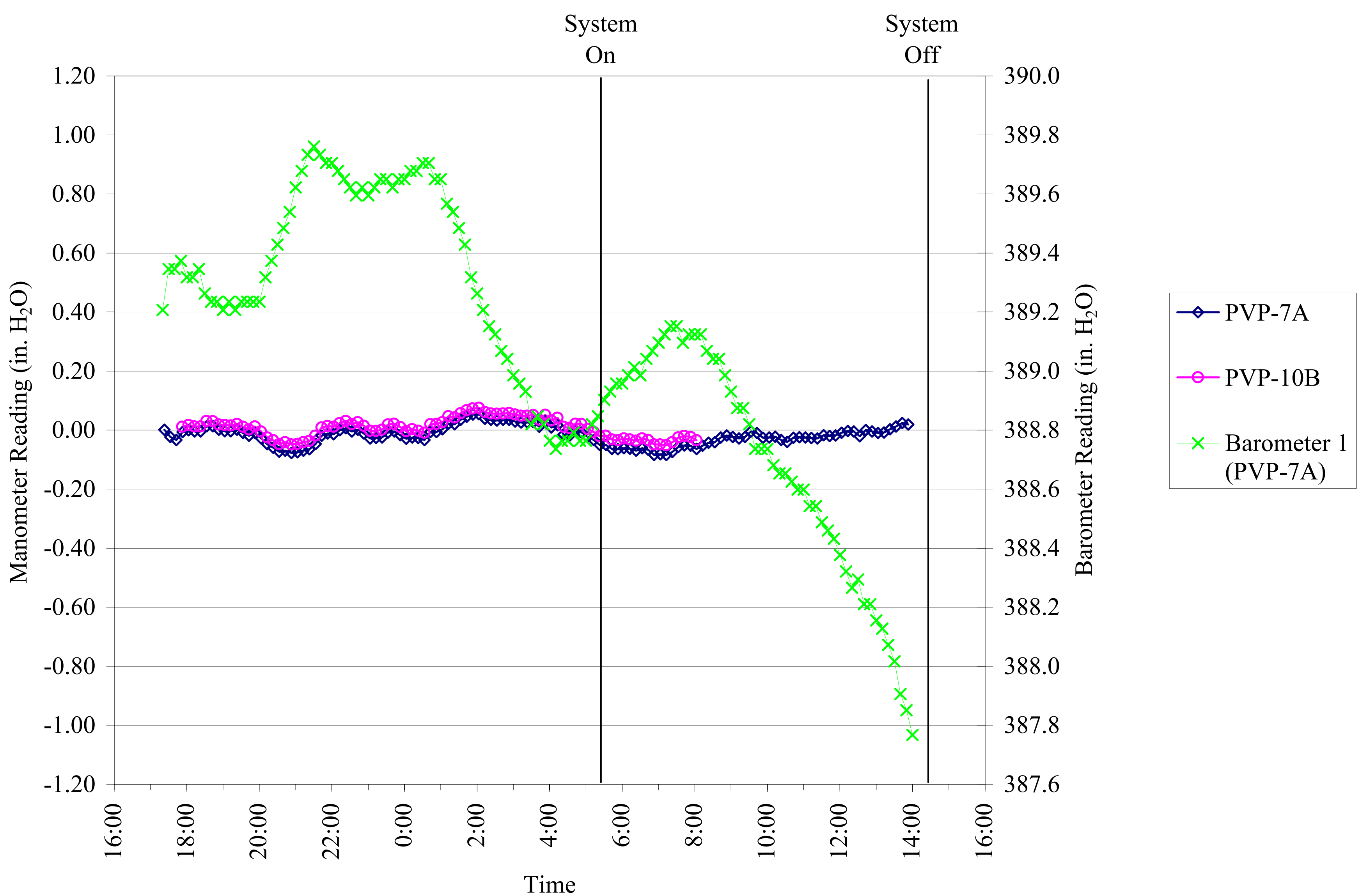


Figure 7A
Test 4 Absolute Pressures

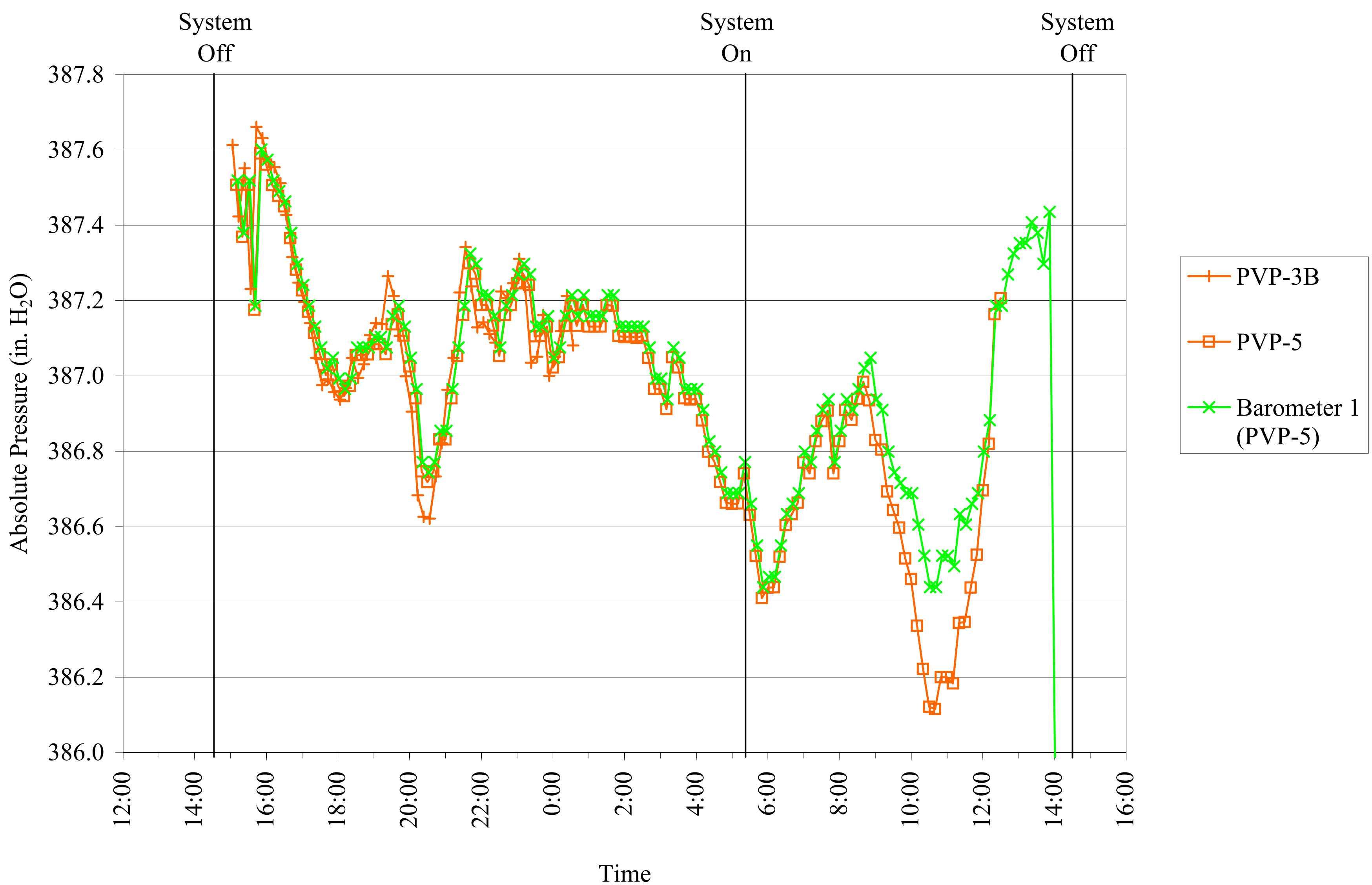


Figure 7B
Test 4 Manometer Data

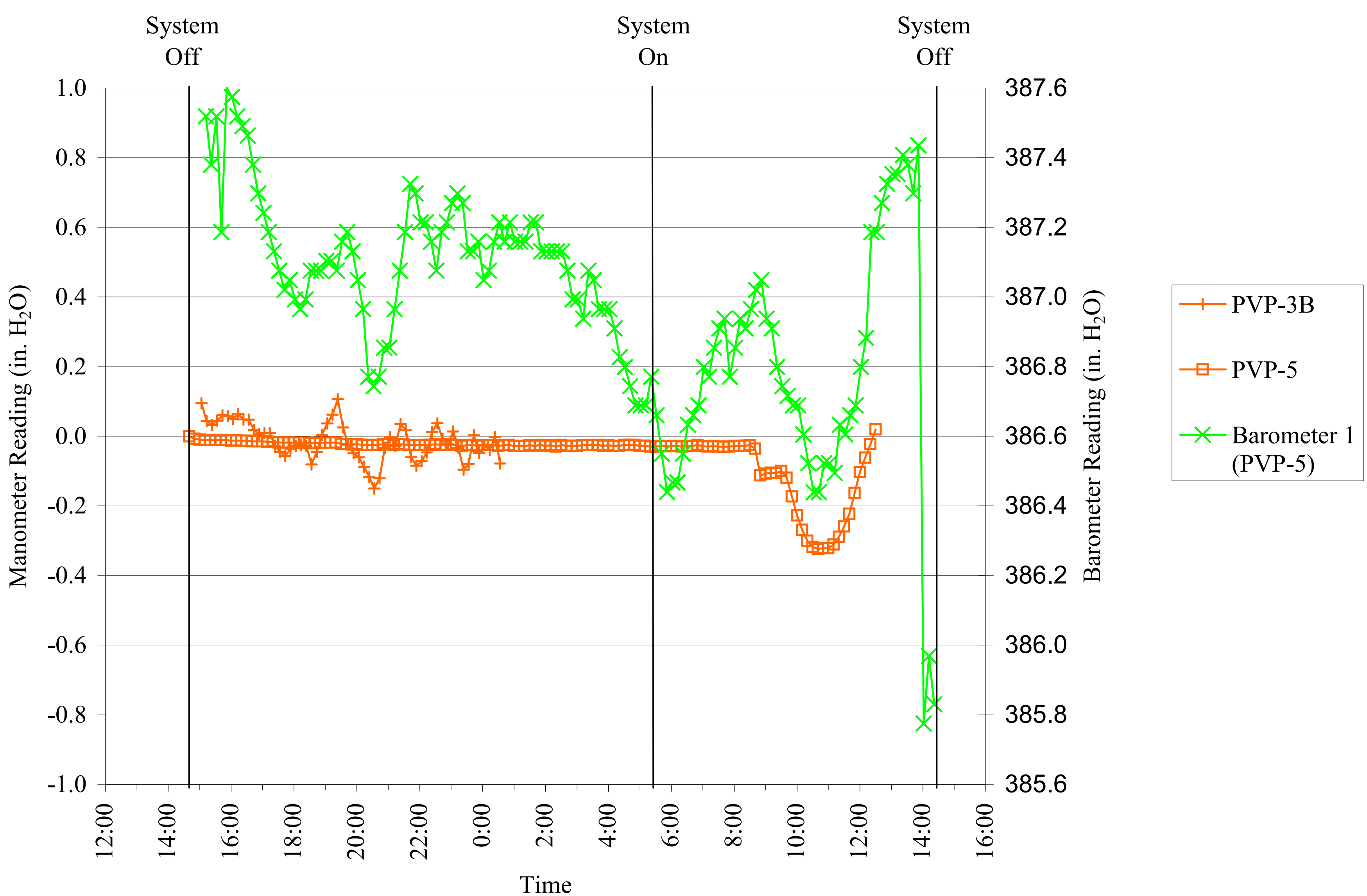


Figure 8A
Test 5 Absolute Pressures

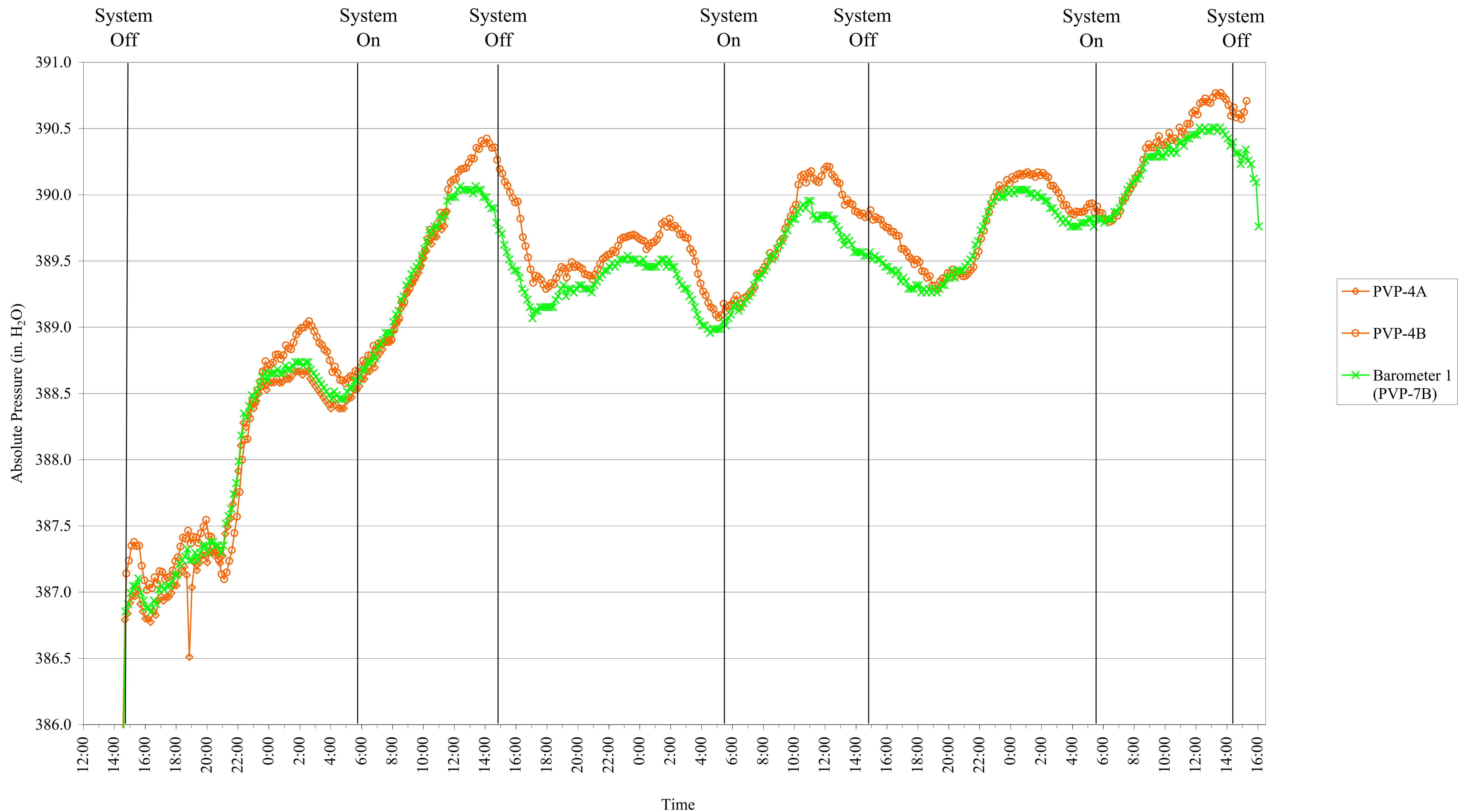


Figure 8B
Test 5 Manometer Data

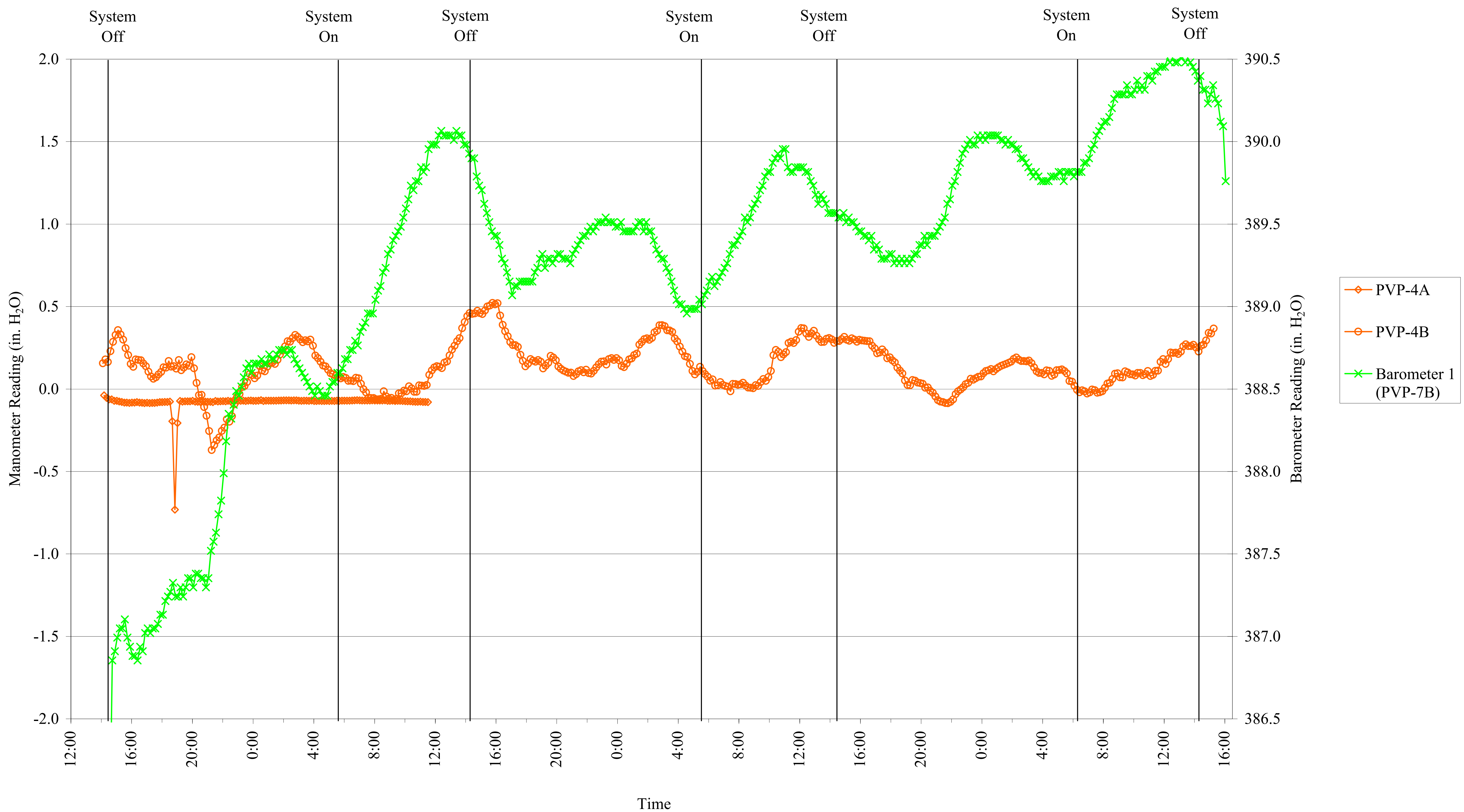


Figure 9A
Test 6 Absolute Pressures

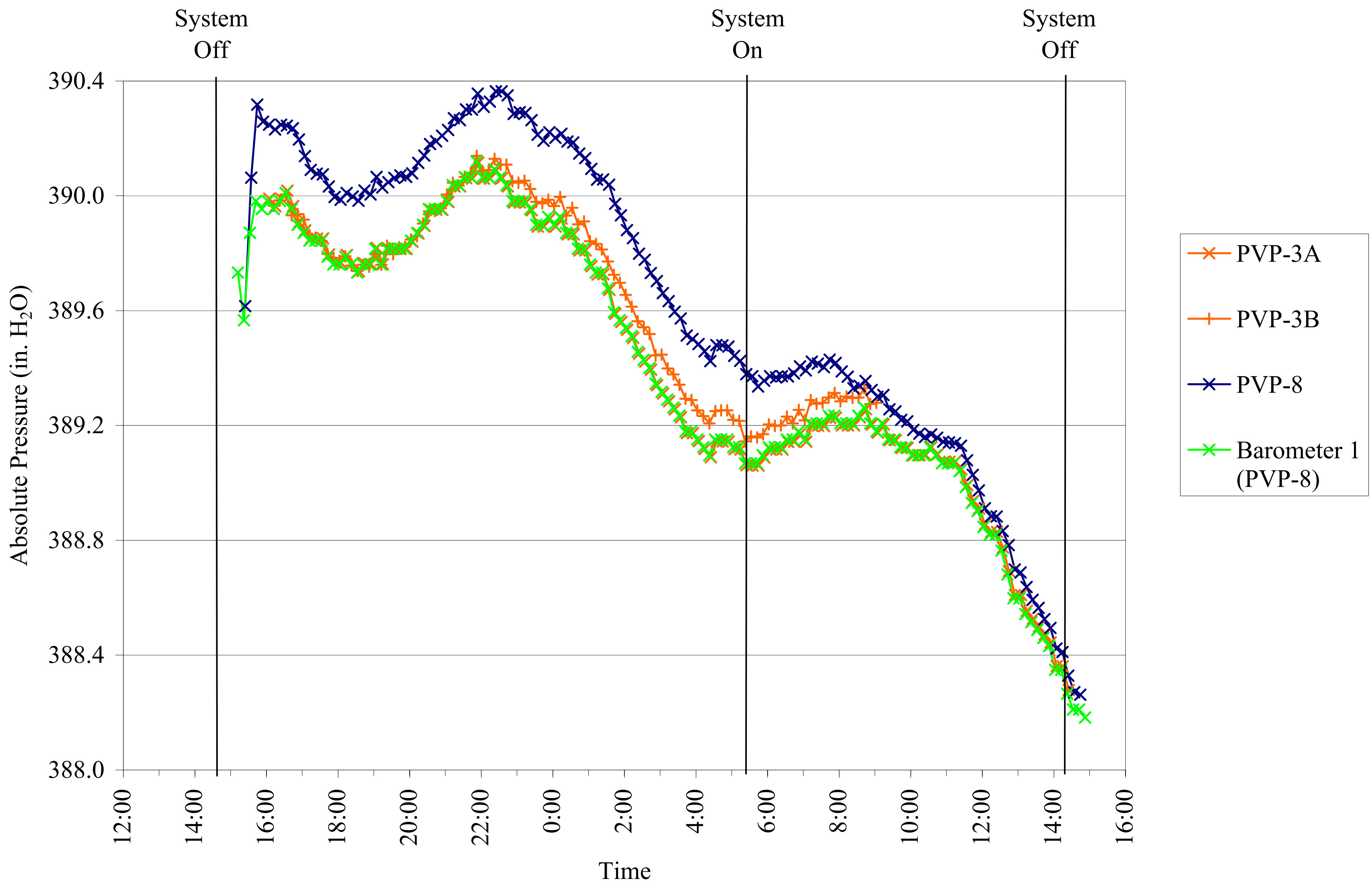


Figure 9B
Test 6 Manometer Data

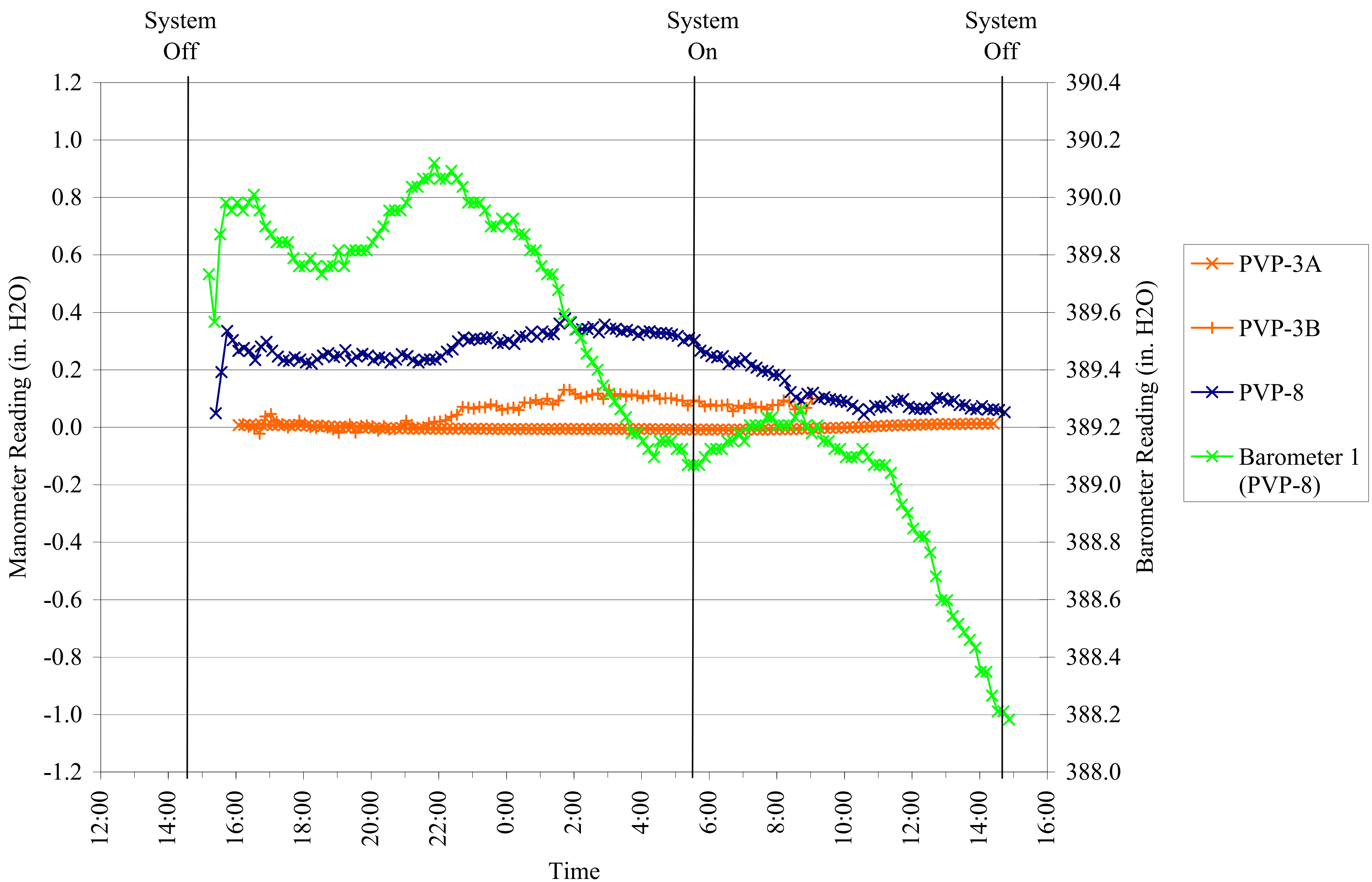


Figure 10A
Test 7 Absolute Pressures

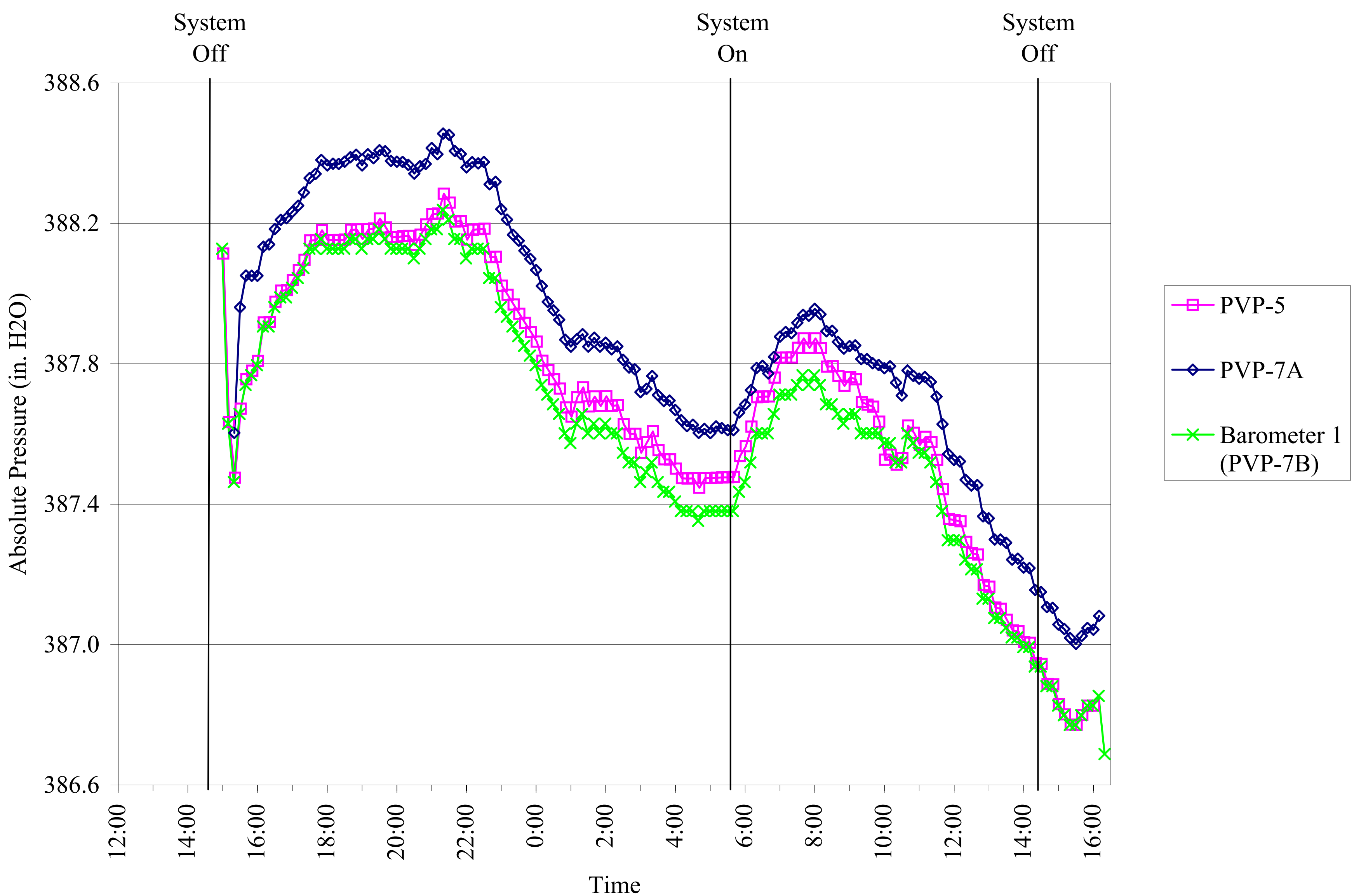


Figure 10B
Test 7 Manometer Data

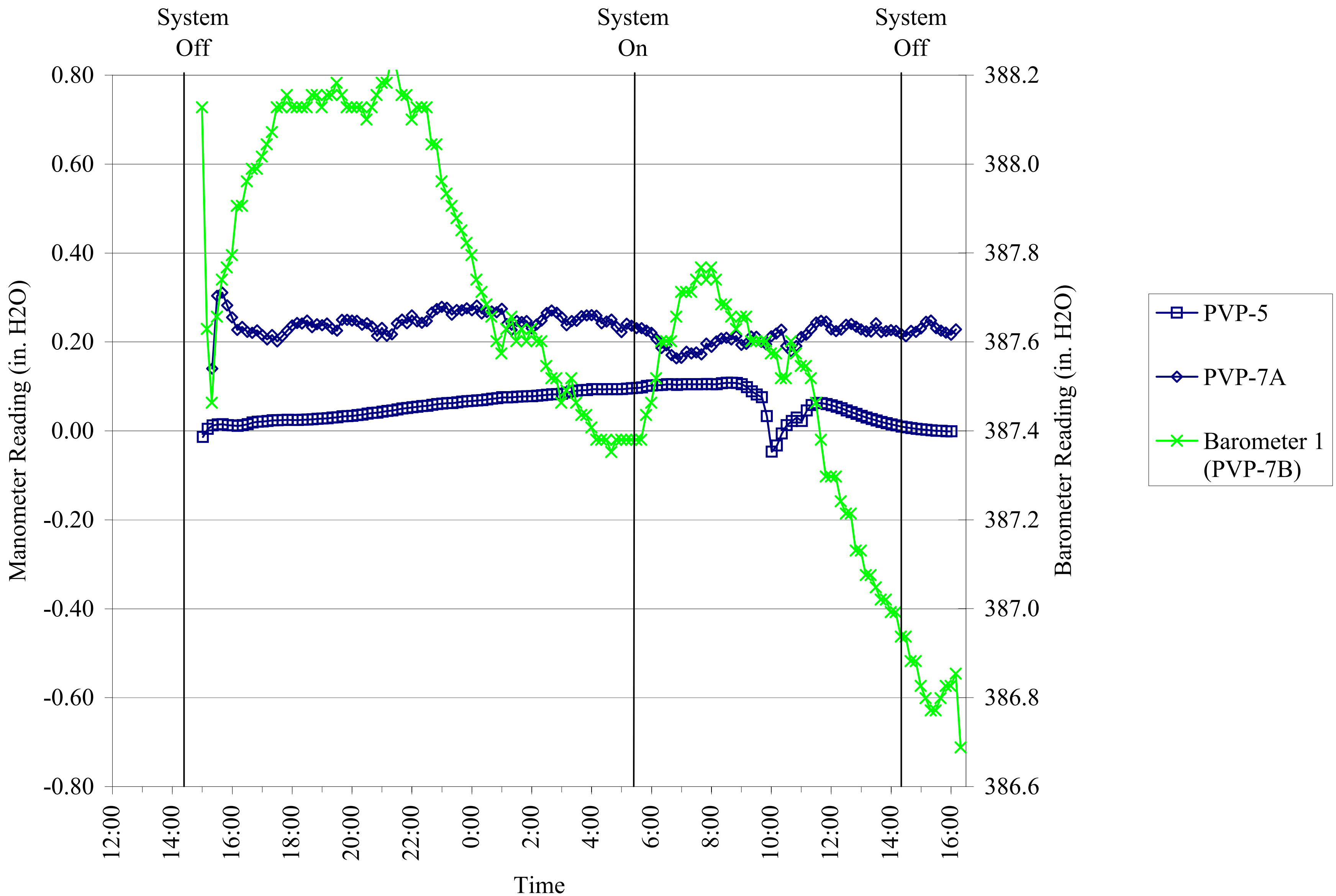


Figure 11A
Test 8 Absolute Pressures

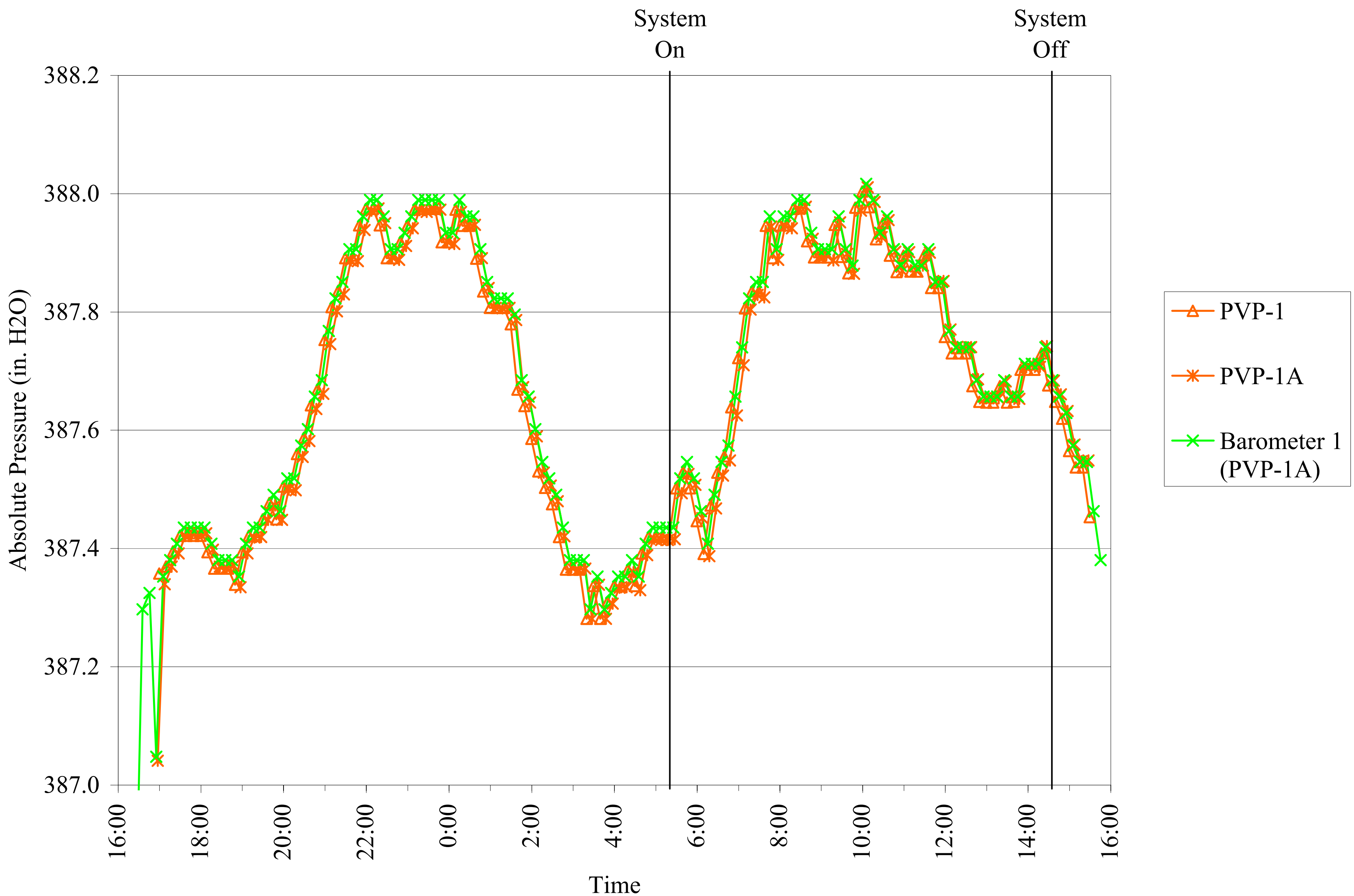


Figure 11B
Test 8 Manometer Data

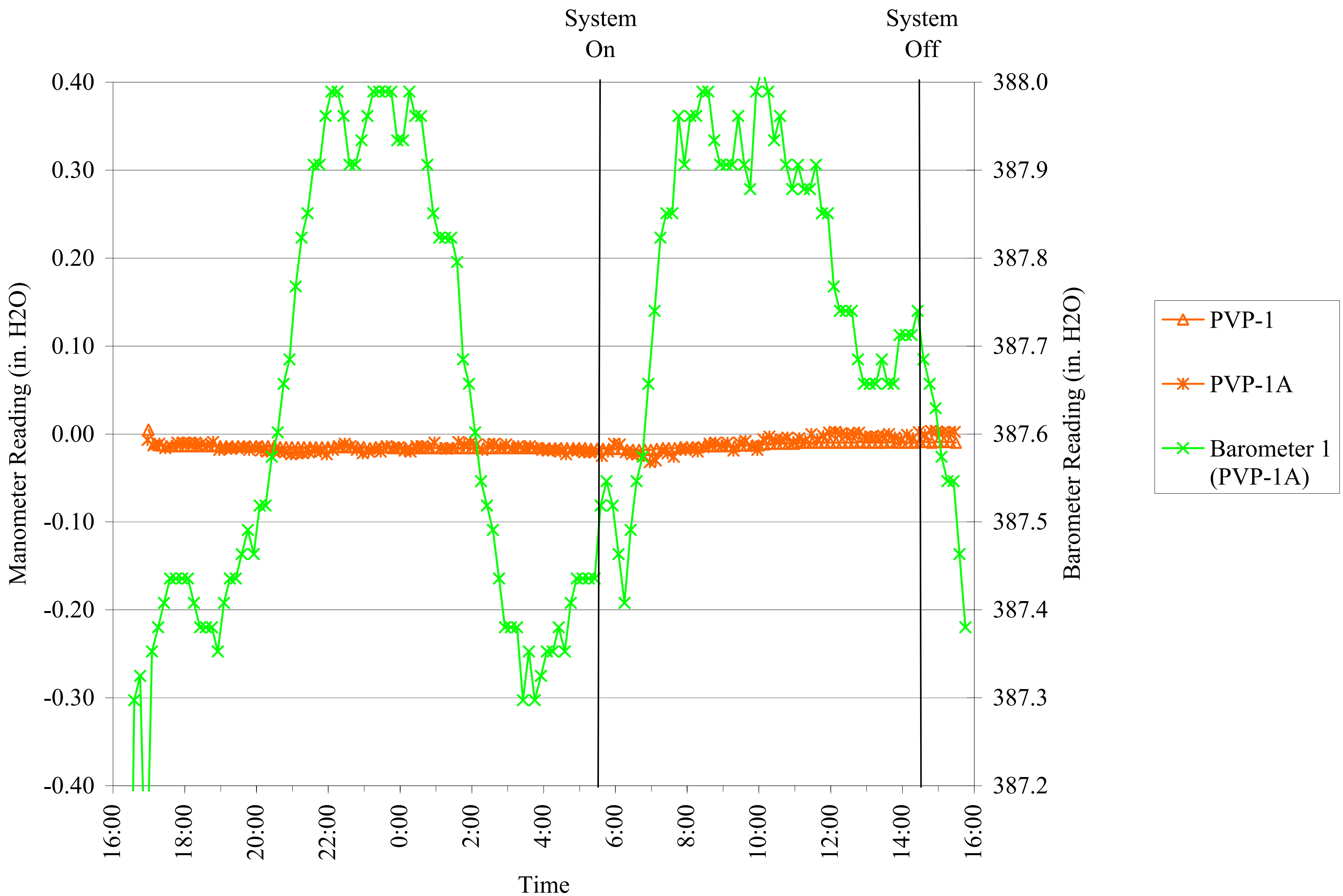


Figure 12A
Test 9 Absolute Pressures

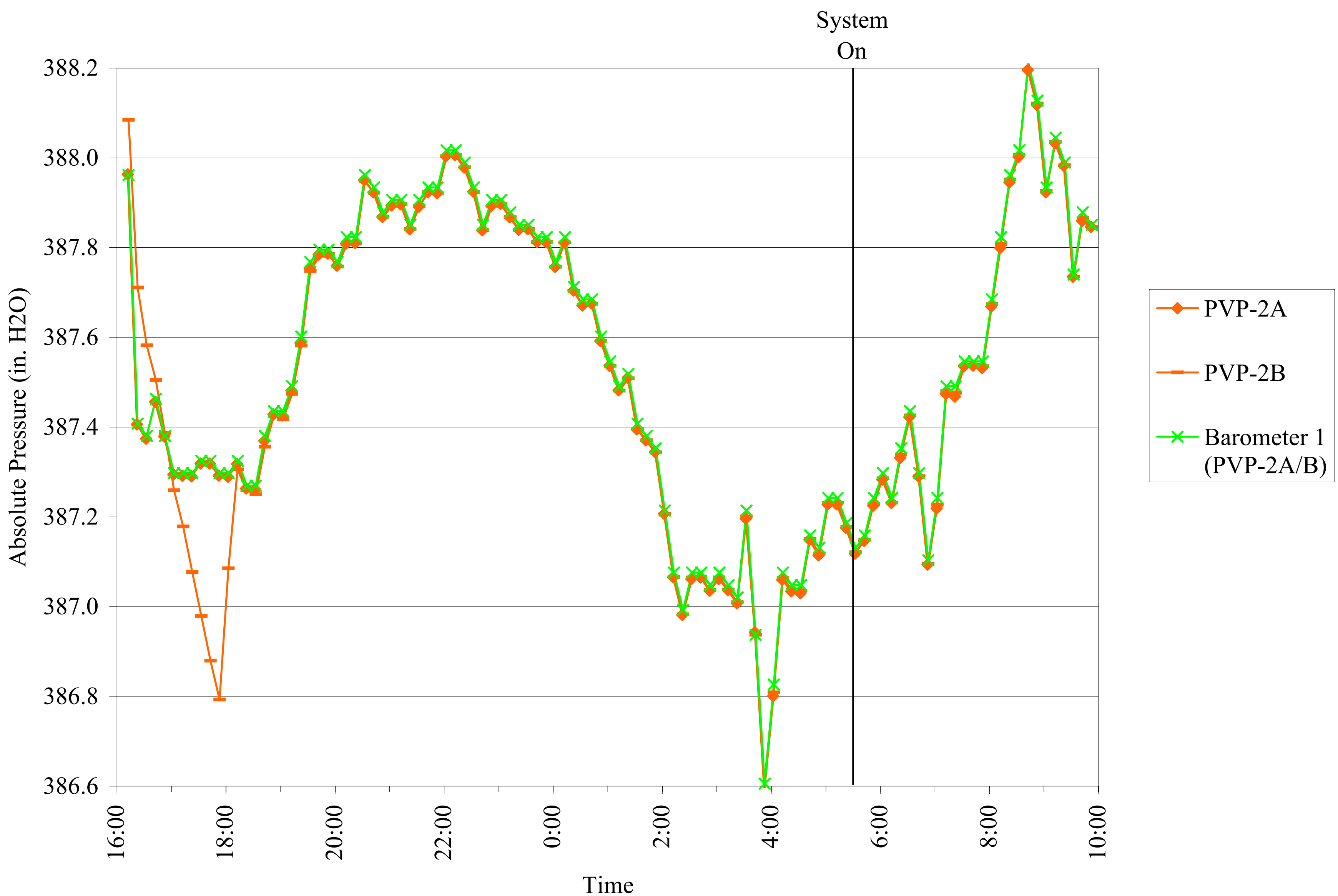


Figure 12B
Test 9 Manometer Data

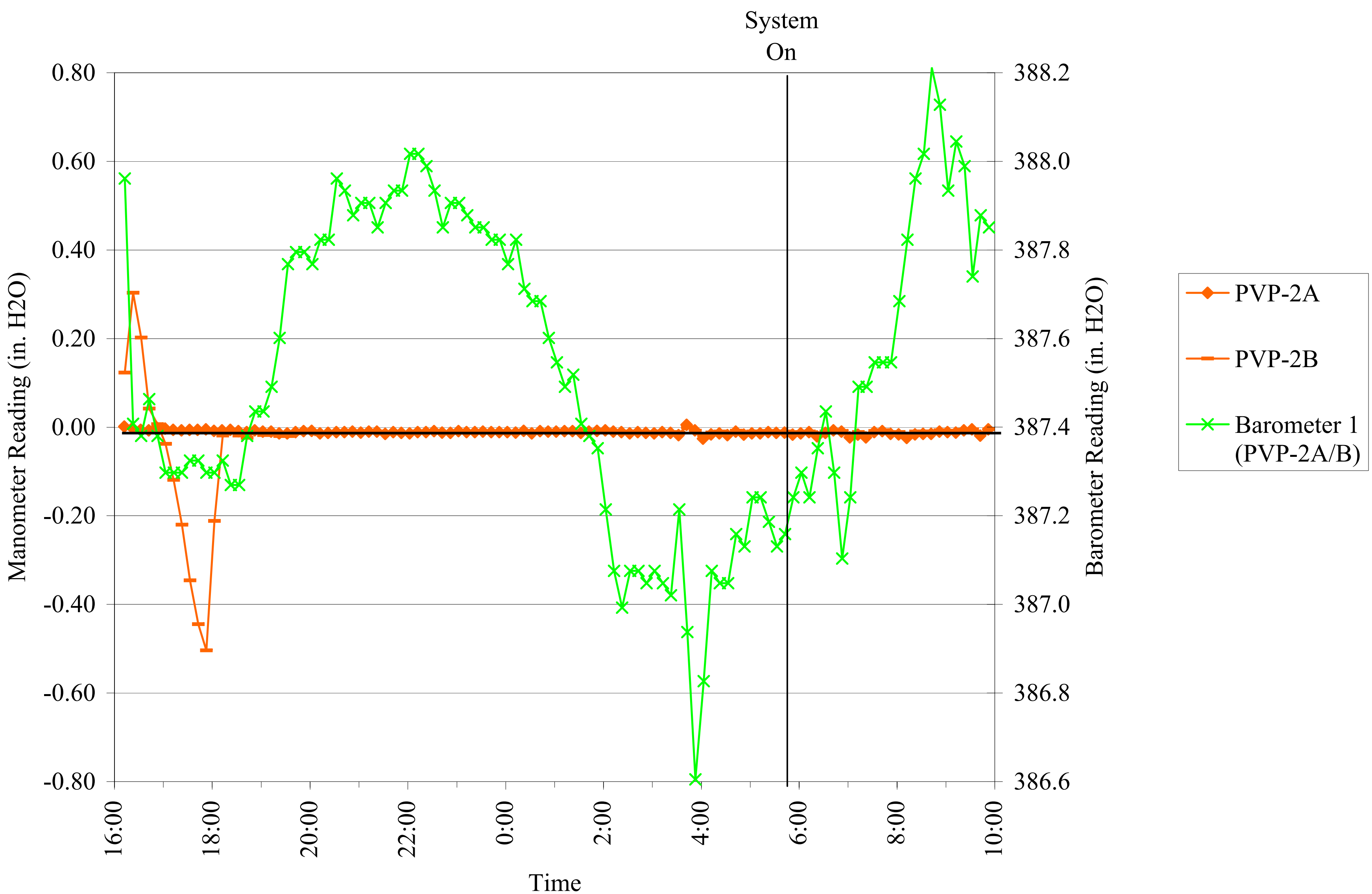


Figure 13A
Test 10 Absolute Pressures

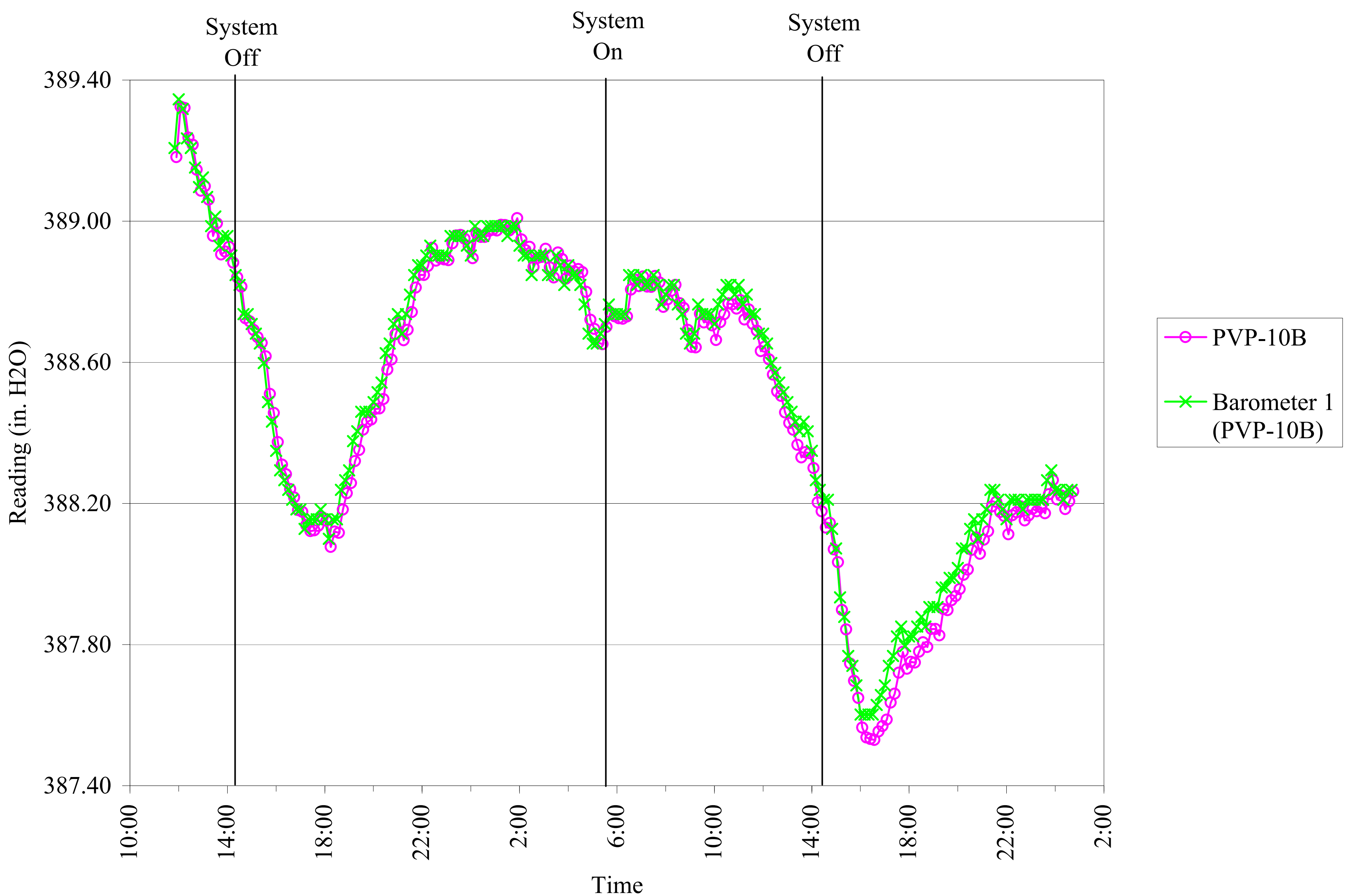


Figure 13B
Test 10 Manometer Data

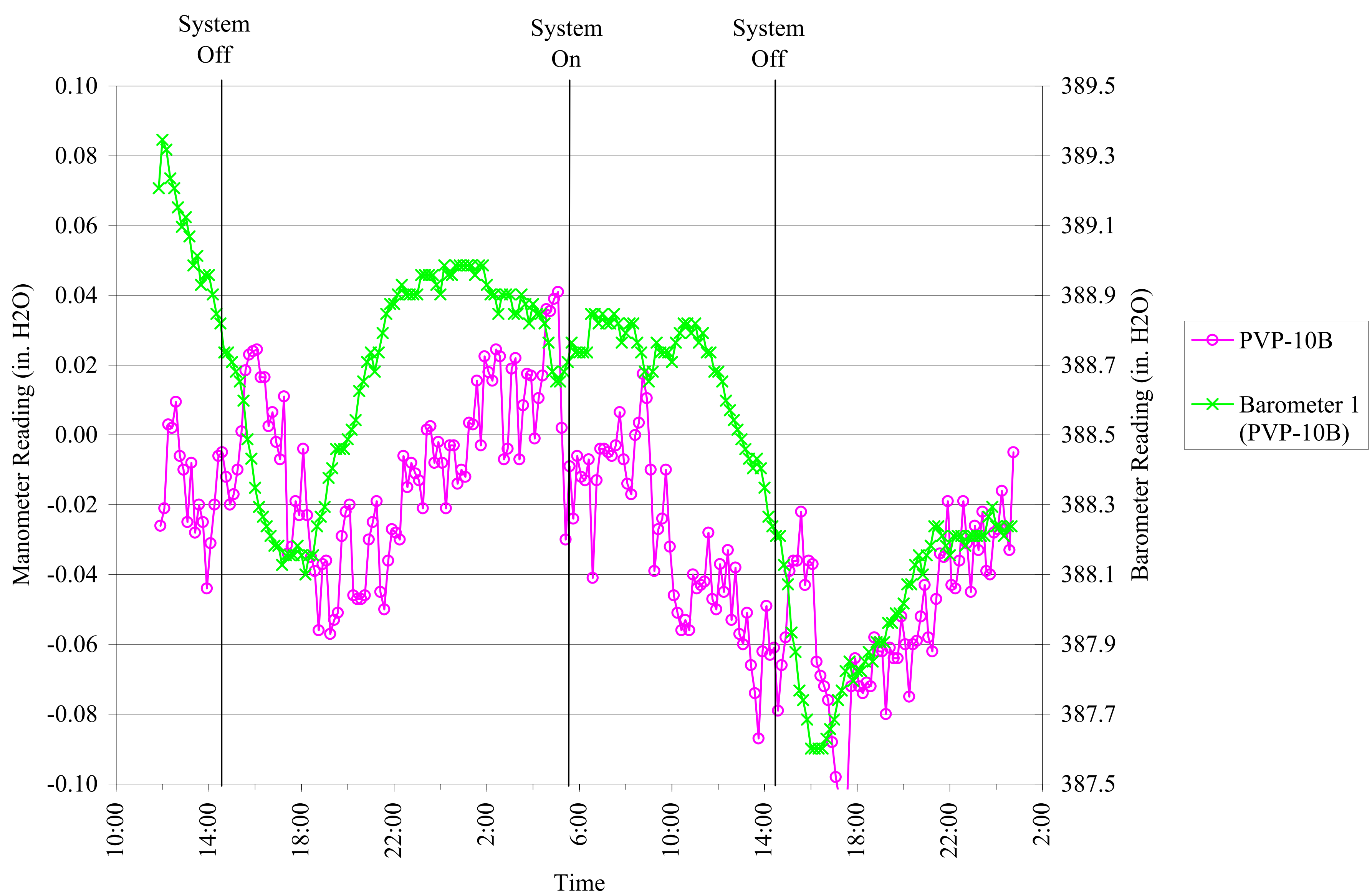


Figure 14A
Test 11 Absolute Pressures

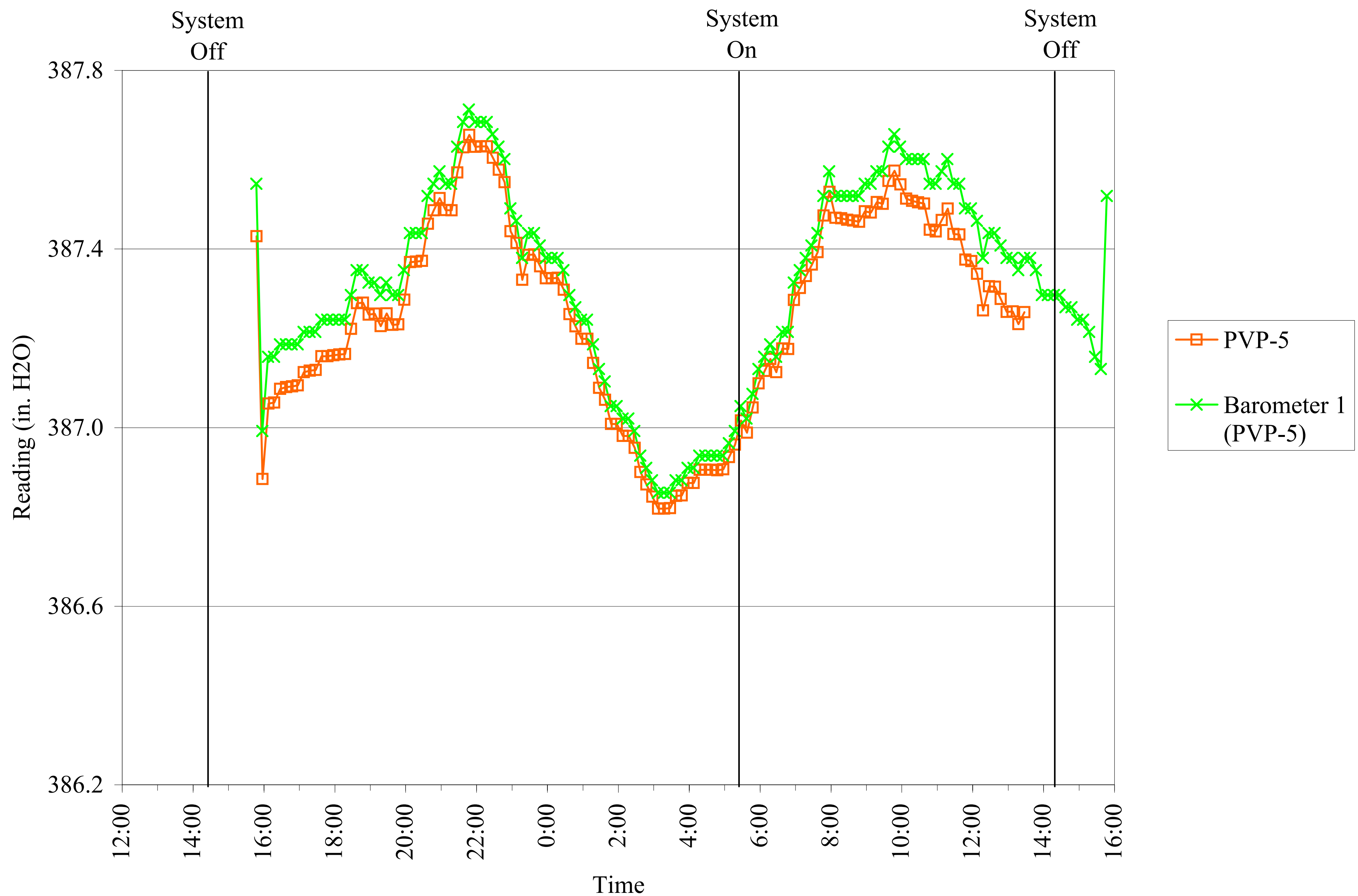


Figure 14B
Test 11 Manometer Data

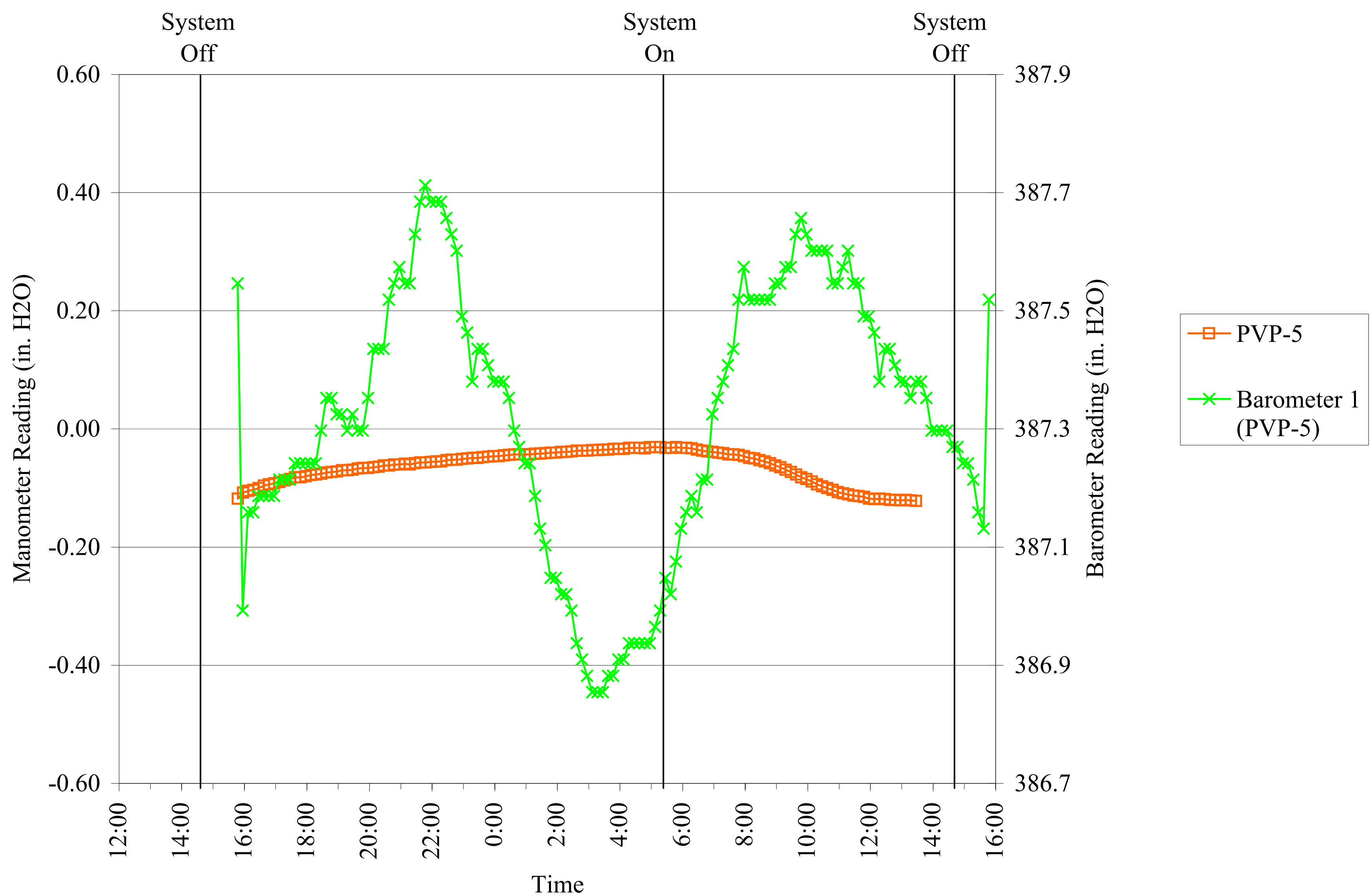


Figure 15A
Test 12 Absolute Pressures

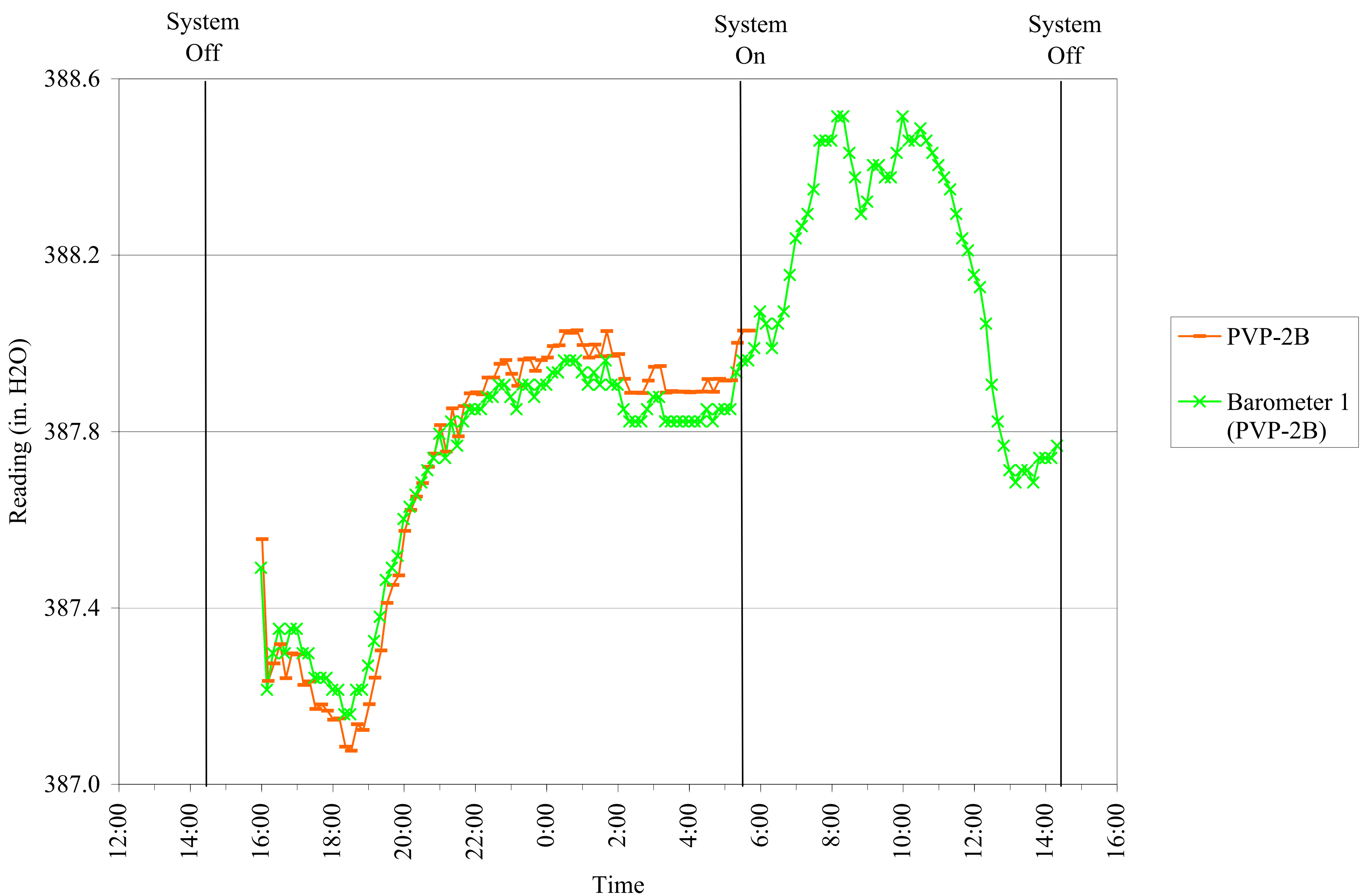


Figure 15B
Test 12 Manometer Data

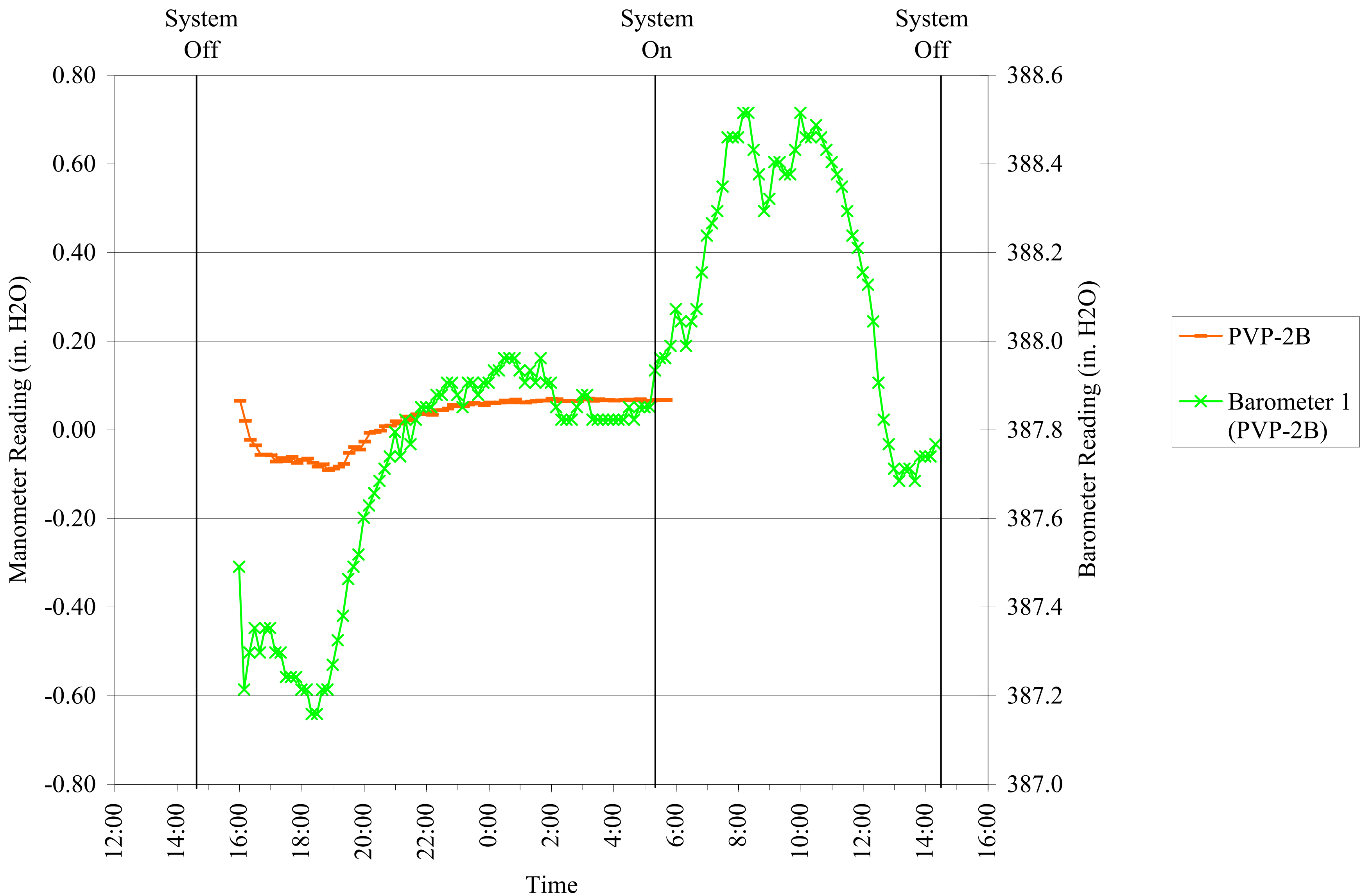


Figure 16A
Test 13 Absolute Pressures

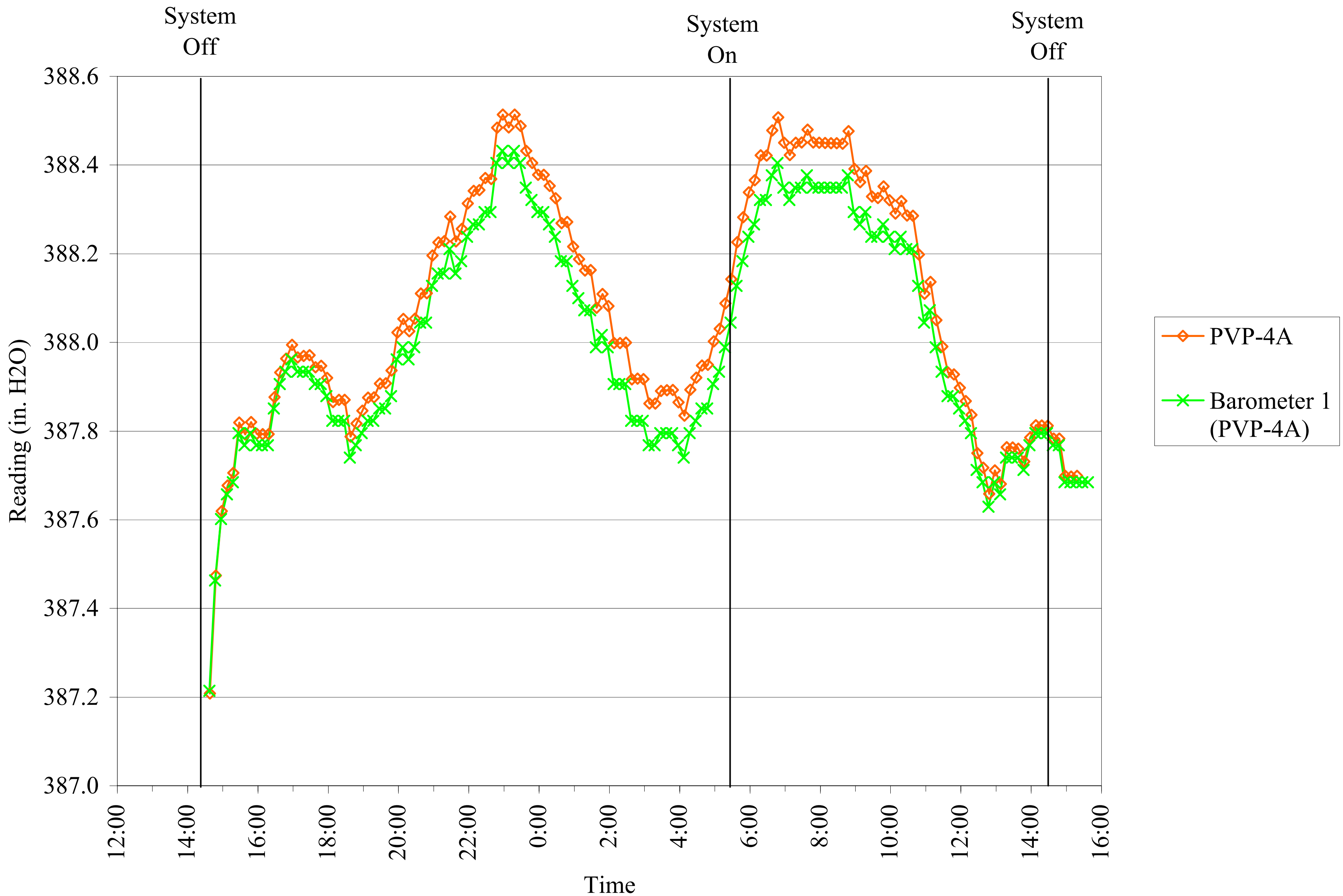


Figure 16B
Test 13 Manometer Data

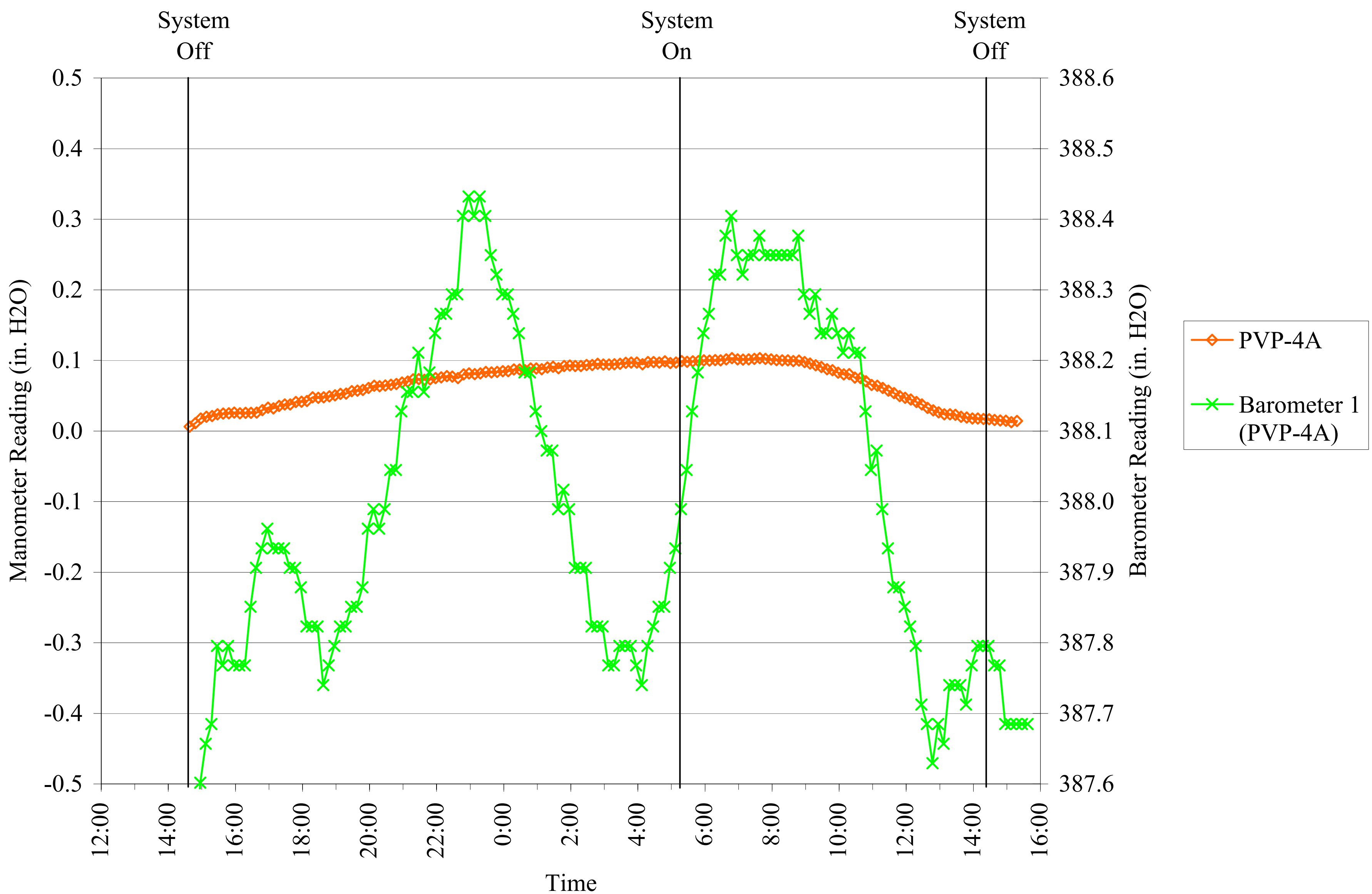


Figure 17A
Test 14 Absolute Pressures

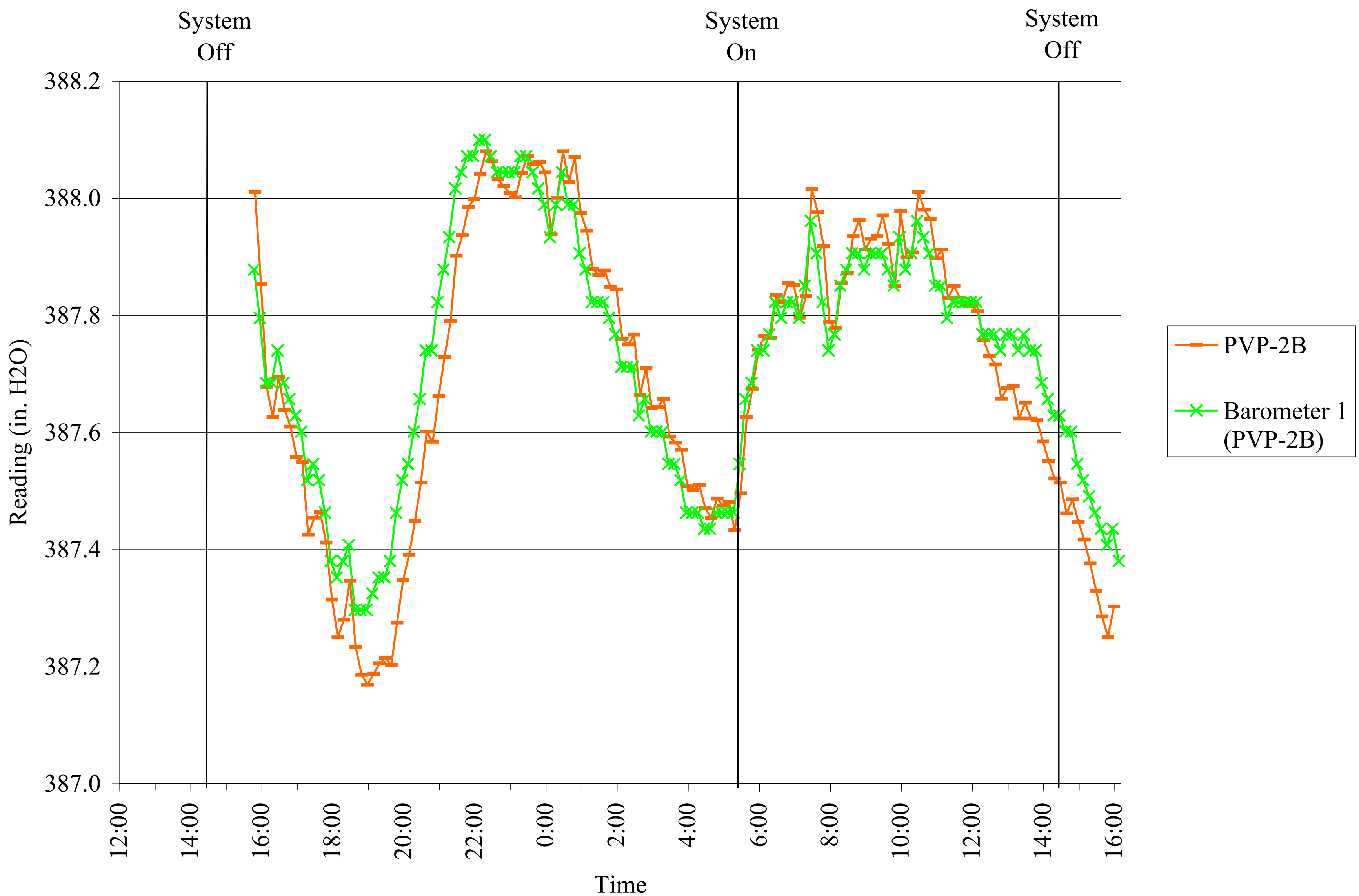


Figure 17B
Test 14 Manometer Data